

# RECLAMATION

*Managing Water in the West*

## DRAFT User's Manual for GSTAR-1D 1.1.3

**Generalized Sediment Transport for Alluvial Rivers – One Dimension, Version 1.1.3**



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US Department of Interior  
Bureau of Reclamation  
Technical Service Center  
Sedimentation and River Hydraulics Group

September 2006

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# **DRAFT User's Manual for GSTAR-1D 1.1.3**

**Generalized Sediment Transport for Alluvial Rivers – One Dimension, Version 1.1.3**

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**US Department of Interior**  
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September 2006

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# 1 Introduction

## 1.1 Background

GSTAR-1D (Generalized Sediment Transport for Alluvial Rivers – One Dimension) is a one-dimensional hydraulic and sediment transport model for use in natural rivers and manmade canals. It is a mobile boundary model with the ability to simulate steady or unsteady flows, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport, and lateral inflows. EPA (Environmental Protection Agency) and Reclamation (Bureau of Reclamation) were funding partners in the development of the GSTAR-1D model.

GSTAR-1D is the most recent model developed in the GSTAR series. It borrows many ideas and some computer code from the previous versions of GSTARS (Molinis and Yang, 1986; Yang and Simões, 2000; Yang and Simões, 2002), but it has been mostly rewritten and updated. The input format has also changed. Previous versions of the GSTAR model were termed GSTARS and the acronym meant “Generalized Stream Tube model for Alluvial River Simulation.” The name and meaning of the acronym were changed to reflect the general nature of the model and to accommodate future models.

Many other sediment and water routing models, such as the HEC-6 model (U.S. Army Corps of Engineers or USCOE, 1977, 1993), FLUVIAL-12 (Chang, 1998), CONCEPTS (Langendoen, 2000), EFDC1D (Tetra Tech, 2001), and CCHE1D (Wu and Vieira, 2002) have also been developed to solve one-dimensional alluvial river problems. These models generally have many of the same capabilities as GSTAR-1D.

## 1.2 GSTAR-1D Capabilities

GSTAR-1D is a hydraulic and sediment transport numerical model developed to simulate flows in rivers and channels with or without movable boundaries. Some of the model’s capabilities are:

- Computation of water surface profiles in a single channel or multi-channel looped networks.
- Steady and unsteady flows.
- Subcritical flows in a steady hydraulic simulation.
- Subcritical, supercritical, and transcritical flows in an unsteady hydraulic simulation.
- Steady and unsteady sediment transport.
- Transport of cohesive and non-cohesive sediments.
- Cohesive sediment aggregation, deposition, erosion, and consolidation.
- Sixteen different non-cohesive sediment transport equations that are applicable to a wide range of hydraulic and sediment conditions.
- Cross stream variation in hydraulic roughness.
- Fractional sediment transport, bed sorting, and armoring.

- Computation of width changes using theories of minimum stream power and other minimizations.
- Point and non-point sources of flow and sediments.
- Internal boundary conditions, such as time-stage tables, rating curves, weirs, bridges, and radial gates.

### 1.3 Limits of Application

GSTAR-1D is a general numerical model developed to simulate and predict cohesive and non-cohesive sediment transport and related river morphological changes due to natural or human influences. GSTAR-1D is an engineering tool for solving fluvial hydraulic problems with the following limitations:

- (1) GSTAR-1D is a one-dimensional model for flow simulation. It should not be applied to situations where a two-dimensional or three-dimensional model is needed for detailed simulation of local hydraulic conditions.
- (2) GSTAR-1D is based on the sub-channel concept. The phenomena of secondary current, lateral diffusion, and superelevation are ignored.
- (3) Many of the sediment transport modules and concepts used in GSTAR-1D are simplified approximations of real phenomena. Those approximations and their limits of validity are embedded in the model.
- (4) GSTAR-1D is currently compiled to run only within the Windows 2000/XP operating system.
- (5) There are no specific system requirements, but the size of the problem may be limited by the computer memory. Systems with 256 MB or more are usually sufficient.

### 1.4 Acquiring GSTAR-1D

The latest information about GSTAR-1D is placed on the Web and can be found by accessing <http://www.usbr.gov/pmts/sediment> and following the links on the web page. Requests may be sent directly to the Bureau of Reclamation's Sedimentation and River Hydraulics Group (Attention: GSTAR Support, U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, P.O. Box 25007 (D-8540), Denver, CO 80225).

GSTAR-1D is under continuous development and improvement. A user is encouraged to check the GSTAR-1D web page regularly for updates.

### 1.5 Disclaimer

The program GSTAR-1D and information in this manual are developed for use at the Bureau of Reclamation. Reclamation does not guarantee the performance of the program, nor help external users solve their problems. Reclamation assumes no responsibility for the correct use of GSTAR-1D and makes no warranties concerning the accuracy, completeness, reliability, usability, or suitability for any particular purpose of the software or the information contained in this manual. GSTAR-1D is a program that requires engineering expertise to be used correctly.

Like other computer programs, GSTAR-1D is potentially fallible. All results obtained from the use of the program should be carefully examined by an experienced engineer to determine if they are reasonable and accurate. Reclamation will not be liable for any special, collateral, incidental, or consequential damages in connection with the use of the software.

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# 2 Flow Routing

This chapter describes the theoretical basis for the one-dimensional flow solutions used in GSTAR-1D. GSTAR-1D has the capability to solve either the steady or unsteady flow equations. The governing equations for steady flow are presented first, followed by the steady flow numerical methods for a single channel, as well as a channel network. The governing equations of unsteady flows are given next with the numerical solution method for simple and complex river networks. The available boundary conditions are described last.

## 2.1 Steady Flow Solution

GSTAR-1D uses the standard step method to solve the energy equation for steady gradually varied flows. Presently, only subcritical and critical flow profiles are calculated when the steady flow option is used.

### 2.1.1 Governing Equations for a Single River

The energy equation for steady gradually varied flow between downstream cross section 1 and upstream cross section 2 is expressed as:

$$Z_2 + \beta_2 \frac{V_2^2}{2g} - Z_1 - \beta_1 \frac{V_1^2}{2g} = h_f + h_c \quad (2.1)$$

where:  $Z_1, Z_2$  = water surface elevations at cross sections 1 and 2, respectively;  
 $V_1, V_2$  = average velocities at cross sections 1 and 2, respectively;  
 $\beta_1, \beta_2$  = velocity distribution coefficients at cross sections 1 and 2, respectively;  
 $g$  = gravitational acceleration;  
 $h_f$  = friction loss between cross sections 1 and 2, and  
 $h_c$  = contraction or expansion losses between cross sections 1 and 2.

The equation for friction loss may be calculated in two ways as:

$$h_{fa} = \sqrt{S_{f_1} S_{f_2}} (x_2 - x_1) \quad (2.2)$$

$$h_{fb} = \left[ \frac{2Q}{(K_1 + K_2)} \right]^2 (x_2 - x_1) \quad (2.3)$$

where:  $S_{f_1}, S_{f_2}$  = friction slopes at cross sections 1 and 2, respectively;  
 $x_1, x_2$  = streamwise coordinates of cross sections 1 and 2, respectively;  
 $Q$  = flow rate; and  
 $K_1, K_2$  = conveyance at cross sections 1 and 2, respectively.

The actual friction loss used is the minimum of the two:

$$h_f = \min(h_{fa}, h_{fb}) \quad (2.4)$$

For a specific discharge, the conveyance,  $K$ , is used to determine the friction slope in Eq. (2.3):

$$S_f = \left( \frac{Q}{K} \right)^2 \quad (2.5)$$

where  $K$  is computed from the Manning's equation:

$$Q = KS_f^{1/2} = \frac{C_m}{n} AR^{2/3} S_f^{1/2} \quad (2.6)$$

where:  $n$  = Manning's coefficient;

$A$  = cross-sectional area;

$R$  = hydraulic radius ( $A/P$ );

$P$  = wetted perimeter; and

$C_m$  = 1.486 for English units or 1.0 for SI units.

The equation for contraction or expansion losses is expressed as:

$$h_c = C_c \left| \frac{\beta_1 V_1^2}{2g} - \frac{\beta_2 V_2^2}{2g} \right| \quad (2.7)$$

where:  $C_c$  = a user defined contraction or expansion coefficient

The expansion coefficient is used when the velocity head at the downstream section 1 is less than that at the upstream section 2. Conversely, the contraction coefficient is used when the velocity head at the downstream section 1 is greater than that at the upstream section 2. This is similar to the way HEC-RAS treats energy loss.

## 2.1.2 Numerical Method for a Single River

Standard step method is used to solve Eq. (2.1), which can be expressed as:

$$f(Z_2) = Z_2 + \beta_2 \frac{V_2^2}{2g} - Z_1 - \beta_1 \frac{V_1^2}{2g} - h_f - h_c = 0 \quad (2.8)$$

This nonlinear algebraic equation can be solved by the Newton-Raphson iterative method (Jain, 2000). Let  $Z_2^*$  be an estimate of  $Z_2$ , the Newton-Raphson method gives a better estimate of  $Z_2$  using the following:

$$Z'_2 = Z_2^* - \frac{f(Z_2^*)}{f'(Z_2^*)} \quad (2.9)$$

where:  $f'(Z_2^*) = 1 - \beta_2 \frac{V_2^2}{gR} - \frac{\partial h_f}{\partial Z_2}$  (2.10)

After the first 2 iterations, the derivative in Eq (2.10) is computed by using the previous 2 values of  $f(Z_2)$ . After the updated  $Z'_2$  is found, it is checked to see if the flow at that cross section is supercritical. If it is, then the depth is set to either critical depth or normal depth, depending upon the input given by the user (see Data Group 1 in Chapter 5). The iteration continues until a preset accuracy is obtained. The model automatically switches to a bisection method if the method described above does not reach a convergent solution.

### 2.1.3 Governing Equations For River Networks

GSTAR-1D provides solutions to both dendritic networks and looped networks. The method used by GSTAR-1D for such networks is similar to that found in Chaudhry (1993). However, some modifications were made to handle large numbers of connections within a river network.

The following strategy is used to record the network connection information. River numbering is in ascending order from upstream to downstream. The boundary condition for each river entering a junction is the ID numbers of the other rivers entering that junction. If the flow is into the junction, the ID number is positive and if the flow is out of the junction the ID number is negative. In a looped network where the flow direction is unknown before the numerical simulation, the input flow direction can be assumed by the user. A calculated positive discharge means that the assumed flow direction is correct. A negative discharge indicates a flow direction opposite of that initially assumed.

A numerical solution of flow in a network requires the calculation of both the energy equation and the continuity equation. At each cross section, the flow depth and flow discharge are initially unknown. The energy equation and the continuity equation are written for each cross section as:

$$F_i = Z_{i+1} - Z_i + \frac{1}{2g} \left( \frac{\beta_{i+1} Q_{i+1} |Q_{i+1}|}{A_{i+1}^2} - \frac{\beta_i Q_i |Q_i|}{A_i^2} \right) + h_f + \frac{C_c}{4g} \left( \frac{Q_{i+1} |Q_{i+1}|}{A_{i+1}^2} + \frac{Q_i |Q_i|}{A_i^2} \right) = 0 \quad (2.11)$$

$$G_i = Q_{i+1} - Q_i - Q_{Lat_i} = 0 \quad (2.12)$$

where  $Q_{Lat_i}$  = the lateral inflow at the reach between cross sections  $i$  and  $i+1$ .

Since  $A$  and  $R$  are functions of only water surface elevation  $Z$ , the unknowns are water surface elevation and discharge. For a river with  $N+1$  cross-sections, there are  $2(N+1)$  unknowns, but only  $2N$  equations for  $N$  river reaches. Therefore, two boundary conditions are required for a unique solution of the system and these can be written in a general form as:

$$BU = f(Q_1, Z_1) = 0 \quad (2.13)$$

$$BD = f'(Q_{N+1}, Z_{N+1}) = 0 \quad (2.14)$$

where  $f$  and  $f'$  are functions defined by the boundary conditions and  $BU$  and  $BD$  signify the upstream and downstream boundary conditions, respectively.

## 2.1.4 Numerical Method for a Network

### 2.1.4.1 Internal sections

By expanding Eqs. (2.11) to (2.14) in Taylor series, the system of equations become:

$$\left[ \begin{array}{cccc|cc} \frac{\partial BU}{\partial Z_1} & \frac{\partial BU}{\partial Q_1} & & & & \\ \frac{\partial F_1}{\partial Z_1} & \frac{\partial F_1}{\partial Q_1} & \frac{\partial F_1}{\partial Z_2} & \frac{\partial F_1}{\partial Q_2} & & \\ \frac{\partial G_1}{\partial Z_1} & \frac{\partial G_1}{\partial Q_1} & \frac{\partial G_1}{\partial Z_2} & \frac{\partial G_1}{\partial Q_2} & & \\ \vdots & \vdots & \ddots & \vdots & & \\ & & & \frac{\partial G_N}{\partial Z_N} & \frac{\partial G_N}{\partial Q_N} & \frac{\partial G_N}{\partial Z_{N+1}} & \frac{\partial G_N}{\partial Q_{N+1}} \\ & & & \frac{\partial G_N}{\partial Z_N} & \frac{\partial G_N}{\partial Q_N} & \frac{\partial G_N}{\partial Z_{N+1}} & \frac{\partial G_N}{\partial Q_{N+1}} \\ & & & \frac{\partial BD}{\partial Z_{N+1}} & \frac{\partial BD}{\partial Q_{N+1}} & & \end{array} \right] \begin{bmatrix} \Delta Z_1 \\ \Delta Q_1 \\ \Delta Z_2 \\ \vdots \\ \Delta Q_N \\ \Delta Z_{N+1} \\ \Delta Q_{N+1} \end{bmatrix} = - \begin{bmatrix} BU \\ F_1 \\ G_1 \\ \vdots \\ F_N \\ G_N \\ BD \end{bmatrix} \quad (2.15)$$

For a river network, one can add equations to the matrix in Eq. (2.15) for each individual cross section. However, the boundary conditions may contain the river depth or discharge in the connected sections of adjoined rivers. For the energy equation  $F_i$ , the four non-zero partial derivatives at the nodes joining rivers are written as:

$$\frac{\partial F_i}{\partial Z_i} = -1 + Q_i^2 \left( \frac{2\beta_i + C_{ci}}{2g} \frac{B_i}{A_i^3} \right) + \frac{\partial h_f}{\partial Z_i} \quad (2.16)$$

$$\frac{\partial F_i}{\partial Q_i} = -2Q_i \frac{2\beta_i + C_{ci}}{4gA_i^2} + \frac{\partial h_f}{\partial Q_i} \quad (2.17)$$

$$\frac{\partial F_i}{\partial Z_{i+1}} = 1 - Q_{i+1}^2 \left( \frac{2\beta_{i+1} - C_{ci}}{2g} \frac{B_{i+1}}{A_{i+1}^3} \right) + \frac{\partial h_f}{\partial Z_{i+1}} \quad (2.18)$$

$$\frac{\partial F_i}{\partial Q_{i+1}} = 2Q \left( \frac{2\beta_{i+1} - C_{ci}}{4gA_{i+1}^2} \right) + \frac{\partial h_f}{\partial Q_{i+1}} \quad (2.19)$$

For the continuity equation  $G_i$ , the two non-zero partial derivatives are written as:

$$\frac{\partial G_i}{\partial Q_i} = -1 \quad (2.20)$$

$$\frac{\partial G_i}{\partial Q_{i+1}} = 1 \quad (2.21)$$

### 2.1.4.2 Upstream Boundary Conditions

For each individual river in a network, one upstream and one downstream boundary condition are required. If the upstream or downstream boundary is a junction, then the ID numbers of the other rivers comprising that junction are entered into the input file. Figure 2.1 illustrates a simple network where one river splits into two.

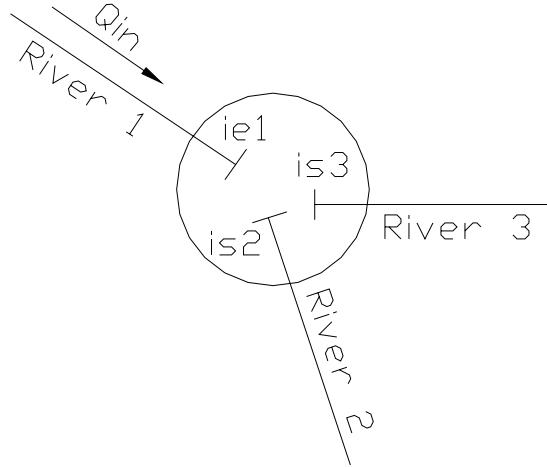


Figure 2.1 Upstream boundaries of River 2 and River 3

River 1 enters into the junction and *ie1* is the last cross section of River 1. The first cross sections of rivers 2 and 3 are *is2* and *is3*, respectively. Two equations are necessary to define the flow rates and water surface elevations at the junction. The equations used are the continuity equation and the energy equation, assuming no energy loss. They can be written as:

$$BU_2 = Q_{is2} + Q_{is3} - Q_{in} = 0 \quad (2.22)$$

$$BU_3 = Z_{is3} + \frac{\beta_{is3}Q_{is3}^2}{2gA_{is3}^2} - Z_{is2} - \frac{\beta_{is2}Q_{is2}^2}{2gA_{is2}^2} = 0 \quad (2.23)$$

The non-zero partial derivatives in the matrix are:

$$\frac{\partial BU_2}{\partial Q_{is2}} = \frac{\partial BU_2}{\partial Q_{is3}} = 1 \quad (2.24)$$

$$\frac{\partial BU_3}{\partial Z_{is2}} = -1 + \frac{\beta_{is2}Q_{is2}^2B_{is2}}{gA_{is2}^3} \quad (2.25)$$

$$\frac{\partial BU_3}{\partial Q_{is2}} = -\frac{\beta_{is2}Q_{is2}}{gA_{is2}^2} \quad (2.26)$$

$$\frac{\partial BU_3}{\partial Z_{is3}} = 1 - \frac{\beta_{is3}Q_{is3}^2B_{is3}}{gA_{is3}^3} \quad (2.27)$$

$$\frac{\partial BU_3}{\partial Q_{is3}} = \frac{\beta_{is3}Q_{is3}}{gA_{is3}^2} \quad (2.28)$$

If there are other rivers in the network, each river has an additional energy equation for the upstream boundary. For a complex network where the upstream incoming discharge is unknown, the partial derivative of the continuity equation is also a function of the discharge of the upstream river.

#### 2.1.4.3 Downstream Boundary Conditions

For each river in the network, the energy equation is used as the downstream boundary condition:

$$BD = Z_{ie} + \frac{\beta_{ie} Q_{ie}^2}{2gA_{ie}^2} - Z_{is} - \frac{\beta_{is} Q_{is}^2}{2gA_{is}^2} = 0 \quad (2.29)$$

where *ie* and *is* denote the cross-sections of the upstream and downstream rivers, respectively, that comprise the junction.

The non-zero partial derivatives in the matrix are:

$$\frac{\partial BD}{\partial Z_{ie}} = 1 - \frac{\beta_{ie} Q_{ie}^2 B_{ie}}{g A_{ie}^3} \quad (2.30)$$

$$\frac{\partial BD}{\partial Q_{ie}} = -\frac{\beta_{ie} Q_{ie}}{g A_{ie}^2} \quad (2.31)$$

$$\frac{\partial BD}{\partial Z_{is}} = -1 + \frac{\beta_{is} Q_{is}^2 B_{is}}{g A_{is}^3} \quad (2.32)$$

$$\frac{\partial BD}{\partial Q_{is}} = -\frac{\beta_{is} Q_{is}}{g A_{is}^2} \quad (2.33)$$

## 2.2 Unsteady Flow Solution

GSTAR-1D also has the ability to simulate unsteady flow. The theoretical basis for the unsteady flow solution is described below.

### 2.2.1 Governing Equations

One-dimensional river flows are described by the de St Venant equations,

$$\text{Continuity: } \frac{\partial(A + A_d)}{\partial t} + \frac{\partial Q}{\partial x} = q_{lat} \quad (2.34)$$

$$\text{Momentum: } \frac{\partial Q}{\partial t} + \frac{\partial(\beta Q^2 / A)}{\partial x} + gA \frac{\partial Z}{\partial x} = -gAS_f \quad (2.35)$$

where:  $Q$  = discharge ( $\text{m}^3/\text{s}$ ),

$A$  = cross section area ( $\text{m}^2$ ),

$A_d$  = ineffective cross section area ( $\text{m}^2$ ),

$q_{lat}$  = lateral inflow per unit length of channel ( $\text{m}^2/\text{s}$ ),

$t$  = time independent variable (s),

$x$  = spatial independent variable (m),

$g$  = gravity acceleration ( $\text{m/s}^2$ ),

$\beta$  = velocity distribution coefficients,

$Z$  = water surface elevation (m),

$S_f$  = energy slope ( $= \frac{Q|Q|}{K^2}$ ), and

$K$  = conveyance ( $\text{m}^3/\text{s}$ ).

## 2.2.2 Numerical Scheme

The numerical scheme used in GSTAR-1D was taken from the “NewC” scheme by Kutija and Newett (2002). There are many numerical methods available to solve the St Venant equations. To model transcritical flow, the conservative form of the momentum equations should be solved (see discussion of the NewC scheme by Meselhe et al. 2005). However, transcritical flows are seldom encountered in natural channels. When they are, it is often in steep mountain streams where it is difficult to obtain sufficiently detailed topography to resolve hydraulic jumps. In addition, the water surface is seldom constant across the cross section in these types of flow and the 1D flow assumptions are not valid. Therefore, this model is not recommended to obtain detailed hydraulic information near the transition between sub- and super-critical flows. However, the model is stable for both sub- and super-critical flow and will be accurate sufficiently far away from the transition.

The scheme is similar to Kutija and Newett, but the position of  $A$  and  $Q$  points are reversed. In GSTAR-1D,  $A$  points are located at the cross section and  $Q$  points are located at the center of two cross sections. Figure 2.2 shows a staggered grid with  $A$  points placed at the beginning and the end of the domain and known cross sections shown as solid lines.

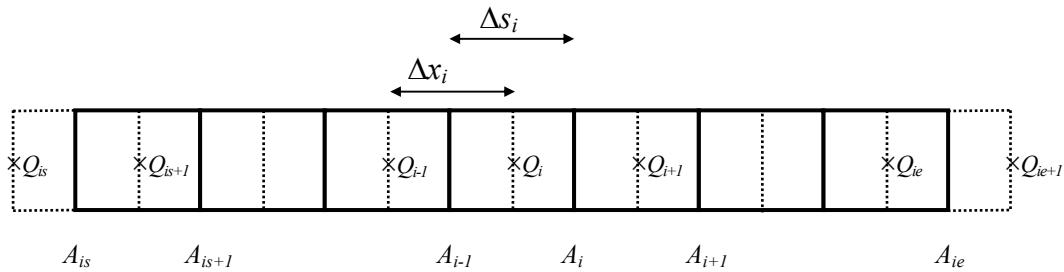


Figure 2.2 Discrete grid for unsteady flow simulation

The discretization of the continuity equation is made with one  $A$ -point and two  $Q$ -points giving the difference equation:

$$A_i^n + A_{di}^n - A_i^{n-1} - A_{di}^{n-1} = -\frac{\Delta t}{\Delta x_i} (\bar{Q}_{i+1} - \bar{Q}_i) \quad (2.36)$$

where the overbar signifies a time weighted averaged value with a weighting factor  $\theta$  in the time dimension. The time weighted discharge,  $\bar{Q}_i$ , can be written as:

$$\bar{Q}_i = \theta Q_i^n + (1-\theta) Q_i^{n-1} \quad (2.37)$$

and Eq. (2.36) can be written in an iteration form, with  $m$  signifying the iteration number;

$$\Delta A_i^m = \alpha_i \Delta Q_i^m + \delta_i \Delta Q_{i+1}^m + \gamma_i \quad (2.38)$$

where the coefficients are:

$$\alpha_i = \frac{\theta \Delta t}{\Delta x_i} \quad (2.38a)$$

$$\delta_i = -\frac{\theta \Delta t}{\Delta x_i} \quad (2.38b)$$

$$\gamma_i = -A_i^n - A_{di}^n + A_i^{n-1} + A_{di}^{n-1} + (\bar{Q}_i - \bar{Q}_{i+1}) \frac{\Delta t}{\Delta x_i} \quad (2.38c)$$

The discrete form of the momentum equation is made with two  $A$ -points and three  $Q$ -points with a weighting factor  $\theta$  in the time dimension giving the difference equation:

$$Q_i^n - Q_i^{n-1} + \frac{\Delta t}{\Delta s_i} (\bar{F}_e - \bar{F}_w) = \Delta t g \frac{\bar{A}_i + \bar{A}_{i-1}}{2} \left( \frac{\bar{Z}_i - \bar{Z}_{i-1}}{\Delta s_i} - S_{fi} \right) \quad (2.39)$$

where:  $\bar{F}_e = \beta \frac{(\bar{Q}_i + \bar{Q}_{i+1})^2}{4\bar{A}_i}$   
 $\bar{F}_w = \beta \frac{(\bar{Q}_i + \bar{Q}_{i-1})^2}{4\bar{A}_{i-1}}$   
 $S_{fi} = \frac{4\bar{Q}_i |\bar{Q}_i|}{(\bar{K}_i + \bar{K}_{i-1})^2}$

Using a weighting factor  $\theta$  in the time dimension, Eq. (2.39) can be written in iteration form as:

$$\begin{aligned} \Delta Q_i^m + \theta \frac{\Delta t}{\Delta x_i} & \left( \frac{\partial \bar{F}_e}{\partial Q_i^n} \Delta Q_i^m + \frac{\partial \bar{F}_e}{\partial Q_{i+1}^n} \Delta Q_{i+1}^m + \frac{\partial \bar{F}_e}{\partial A_i^n} \Delta A_i^m \right. \\ & \left. - \frac{\partial \bar{F}_w}{\partial Q_i^n} \Delta Q_i^m - \frac{\partial \bar{F}_w}{\partial Q_{i-1}^n} \Delta Q_{i-1}^m - \frac{\partial \bar{F}_w}{\partial A_{i-1}^n} \Delta A_{i-1}^m \right) \\ & - \theta \Delta t g \frac{\Delta A_i^m + \Delta A_{i-1}^m}{2} \left( \frac{Z_{i-1}^{n+1} - Z_i^{n+1}}{\Delta s_i} - S_{fi}^{n+1} \right) \\ & - \theta \Delta t g \frac{\bar{A}_i + \bar{A}_{i-1}}{2} \left( \frac{\Delta A_{i-1}^m}{T_{i-1}^{n+1} \Delta s_i} - \frac{\Delta A_i^m}{T_i^{n+1} \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_i^n} \Delta A_i^m \right. \\ & \left. - \frac{\partial \bar{S}_{fi}}{\partial A_{i-1}^n} \Delta A_{i-1}^m - \frac{\partial \bar{S}_{fi}}{\partial Q_i^n} \Delta Q_i^m \right) \\ & = -Q_i^n + Q_i^{n-1} - \frac{\Delta t}{\Delta x_i} (\bar{F}_e - \bar{F}_w) + \Delta t g \frac{\bar{A}_i + \bar{A}_{i-1}}{2} \left( \frac{\bar{Z}_{i-1} - \bar{Z}_i}{\Delta s_i} - \bar{S}_{fi} \right) \end{aligned} \quad (2.40)$$

Substituting Eq. (2.38) into Eq. (2.40), results in:

$$a_i \Delta Q_{i-1}^m + b_i \Delta Q_i^m + c_i \Delta Q_{i+1}^m = d_i \quad (2.41)$$

where the coefficients are:

$$\begin{aligned} a_i &= \theta \frac{\Delta t}{\Delta s_i} \left( -\frac{\partial \bar{F}_w}{\partial Q_{i-1}^n} - \frac{\partial \bar{F}_w}{\partial A_{i-1}^n} \alpha_{i-1} \right) \\ &\quad - \frac{\theta \alpha_{i-1} \Delta t g}{2} \left[ \frac{Z_{i-1}^{n+1} - Z_i^{n+1}}{\Delta s_i} - S_{fi} + \left( \frac{\bar{A}_i + \bar{A}_{i-1}}{2} \right) \left( \frac{1}{T_{i-1} \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_{i-1}^n} \right) \right] \end{aligned} \quad (2.41a)$$

$$\begin{aligned} b_i &= 1 + \theta \frac{\Delta t}{\Delta s_i} \left( \frac{\partial \bar{F}_e}{\partial Q_i^n} + \frac{\partial \bar{F}_e}{\partial A_i^n} \alpha_i - \frac{\partial \bar{F}_w}{\partial Q_i^n} - \frac{\partial \bar{F}_w}{\partial A_{i-1}^n} \delta_{i-1} \right) \\ &\quad - \theta \frac{\Delta t g}{2} (\alpha_i + \delta_{i-1}) \left( \frac{Z_{i-1}^n - Z_i^n}{\Delta s_i} - S_{fi} \right) \end{aligned} \quad (2.41b)$$

$$\begin{aligned} &\quad - \theta \frac{\Delta t g}{2} (\bar{A}_i + \bar{A}_{i-1}) \left[ \delta_{i-1} \left( \frac{1}{T_{i-1} \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_{i-1}^n} \right) + \right. \\ &\quad \left. \alpha_i \left( \frac{-1}{T_i \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_i^n} \right) - \frac{\partial \bar{S}_{fi}}{\partial Q_i^n} \right] \end{aligned}$$

$$\begin{aligned} c_i &= \theta \frac{\Delta t}{\Delta s_i} \left( \frac{\partial \bar{F}_e}{\partial Q_{i+1}^n} + \frac{\partial \bar{F}_e}{\partial A_i^n} \delta_i \right) \\ &\quad - \frac{\theta \delta_i \Delta t g}{2} \left[ \left( \frac{Z_{i-1}^n - Z_i^n}{\Delta s_i} - S_{fi} \right) + \frac{\bar{A}_i + \bar{A}_{i-1}}{2} \left( \frac{-1}{T_i \Delta s_i} - \frac{\partial S_{fi}}{\partial A_i} \right) \right] \end{aligned} \quad (2.41c)$$

$$\begin{aligned} d_i &= Q_i^{n-1} - Q_i^n \\ &\quad + \frac{\Delta t}{\Delta s_i} \left( \bar{F}_w - \bar{F}_e - \theta \gamma_i \frac{\partial \bar{F}_e}{\partial A_i^n} + \theta \gamma_{i-1} \frac{\partial \bar{F}_w}{\partial A_{i-1}^n} \right) \\ &\quad + \frac{\Delta t g}{2} (\bar{A}_i + \bar{A}_{i-1} + \theta \gamma_i + \theta \gamma_{i-1}) \left( \frac{\bar{Z}_{i-1}^n - \bar{Z}_i^n}{\Delta s_i} - \bar{S}_{fi} \right) \\ &\quad + \frac{\theta \Delta t g}{2} (\bar{A}_i + \bar{A}_{i-1}) \left[ \gamma_{i-1} \left( \frac{1}{T_{i-1} \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_{i-1}^n} \right) + \gamma_i \left( \frac{-1}{T_i \Delta s_i} - \frac{\partial \bar{S}_{fi}}{\partial A_i^n} \right) \right] \end{aligned} \quad (2.41d)$$

where  $T$  is the flow top width. For a single channel with  $N+1$  cross sections, there are  $N+2$  unknowns and  $N$  Eqs. (2.41). An upstream and a downstream boundary condition are therefore required.

The method as described above can be unstable for supercritical flow. If supercritical flow is to be simulated, GSTAR-1D uses the Local Partial Inertia (LPI, from Fread and Lewis, 1998) technique to compute the flow. The LPI technique consists of multiplying the convective terms by a parameter,  $\sigma$ , as follows:

$$\sigma \left[ \frac{\partial Q}{\partial t} + \frac{\partial(\beta Q^2 / A)}{\partial x} \right] + gA \frac{\partial Z}{\partial x} = -gAS_f \quad (2.42)$$

$$\sigma = \max(0, 1 - F_r^n) \quad (2.43)$$

where  $F_r$  is the Froude Number and  $n$  is a coefficient. In GSTAR-1D,  $n$  is set to a value of 5. If  $F_r \geq 1$ , then  $\sigma = 0$  and the momentum equation simplifies to the diffusive wave equation for open channel flow. The diffusive wave equation is generally stable for sub- or super-critical flow, but because it ignores the acceleration terms in the momentum equation, it may not accurately simulate the propagation of rapidly changing hydrographs such as may occur during dam breaks. GSTAR-1D assumes that subcritical flow occurs at the boundaries of a river and the user must therefore supply both upstream and downstream boundary conditions. Therefore, supercritical flow should not occur at the upstream or downstream ends of any river.

### 2.2.3 Upstream Boundary Conditions

Two upstream boundary conditions are available: 1. known water discharge; 2. known water surface elevation

#### 2.2.3.1 Water Discharge

The known water discharge boundary condition is summarized as:

$$Q_{is} = f(t) \quad (2.44)$$

where  $Q_{is}$  = the discharge at the center of the left fictitious cell,  $i = 1$ , outside of the model domain. The discretization of the upstream boundary condition written in an iteration form as:

$$\Delta Q_{is} = -Q_{is}^n + f(t_{n+1}) \quad (2.45)$$

The above equation can be written in the following form:

$$a_{is}\Delta Q_{is-1}^m + b_{is}\Delta Q_{is}^m + c_{is}\Delta Q_{is+1}^m = d_{is} \quad (2.46)$$

where the coefficients are:

$$a_{is} = 0$$

$$b_{is} = 1$$

$$c_{is} = 0$$

$$d_{is} = f(t) - Q_{is}^n$$

These coefficients are used to replace the coefficients defined in Eqs. (2.41a) to (2.41d) at the upstream boundary.

#### 2.2.3.2 River Stage

The river stage boundary condition can be written as:

$$H_{is} = f(t) \text{ or } A_{is} = f(t) \quad (2.47)$$

The discretized continuity equation (Eq. 2.38) is used to implement this boundary condition:

$$\alpha_{is} \Delta Q_{is}^m + \delta_{is} \Delta Q_{is+1}^m + \gamma_{is} = \Delta A_{is}^m \quad (2.48)$$

where:  $\Delta A_{is}^m = A_{is}^n - A_{is}^{m-1}$ ;

$A_{is}$  = the given entrance cross section area defined in Eq. (2.47),  
and

$A_{is}^{m-1}$  = the estimated entrance cross section area of last iteration.

The above equation can be written in the following form:

$$a_{is} \Delta Q_{is-1}^m + b_{is} \Delta Q_{is}^m + c_{is} \Delta Q_{is+1}^m = d_{is} \quad (2.49)$$

where the coefficients are:

$$a_{is} = 0$$

$$b_{is} = \alpha_{is}$$

$$c_{is} = \delta_{is}$$

$$d_{is} = \Delta A_{is}^m - \gamma_{is}$$

These coefficients are used to replace the coefficients defined in Eqs. (2.41a) to (2.41d).

## 2.2.4 Downstream Boundary Conditions

The downstream boundary conditions can also be grouped into two general types:  
1. rating curve (the discharge is a function of the river stage); 2. known water surface elevation.

### 2.2.4.1 Rating Curve

The rating curve boundary conditions can be expressed as:

$$Q_{ie+1} = f(A_{ie}) \quad (2.50)$$

where  $Q_{ie+1}$  is the discharge at the center of the right fictitious cell,  $x_{ie+1}$  in Figure 2.2, and  $A_{ie}$  is the exit cross section area as defined in Figure 2.2. The discretization of the downstream boundary condition in iteration form is:

$$\Delta Q_{ie+1} = -Q_{ie+1}^n + f(A_{ie}^n) + \frac{\partial f}{\partial A_{ie}} \Delta A_{ie} \quad (2.51)$$

Expression (2.38) can be used to eliminate the unknown  $\Delta A_{ie}$  in Eq. (2.51), resulting in the following form:

$$a_{ie+1} \Delta Q_{ie}^m + b_{ie+1} \Delta Q_{ie+1}^m + c_{ie+1} \Delta Q_{ie+2}^m = d_{ie+1} \quad (2.52)$$

where the coefficients are:

$$a_{ie+1} = -\frac{\partial f}{\partial A_{ie}} \alpha_{ie}$$

$$b_{ie+1} = 1 - \frac{\partial f}{\partial A_{ie}} \delta_{ie}$$

$$c_{ie+1} = 0$$

$$d_{ie+1} = f(A_{ie}^n) - Q_{ie+1}^n + \frac{\partial f}{\partial A_{ie}} \gamma_{ie}$$

These coefficients are used to replace the coefficients defined in Eqs. (2.41a) to (2.41d) for the downstream boundary.

#### 2.2.4.2 River Stage

The given river stage boundary condition can be written as:

$$H_{ie} = f(t) \quad \text{or} \quad A_{ie} = f(t) \quad (2.53)$$

where  $ie$  = last cross section. The discretized continuity equation (Eq. 2.38) is used to implement the boundary condition.

$$\alpha_{ie} \Delta Q_{ie}^m + \delta_{ie} \Delta Q_{ie+1}^m + \gamma_{ie} = \Delta A_{ie}^m \quad (2.54)$$

where  $\Delta A_{ie}^m = A_{ie} - A_{ie}^{m-1}$  and  $A_{ie}$  is the given cross section area defined in Eq. (2.53).

The above equation can be written in the following form:

$$a_{ie+1} \Delta Q_{ie}^m + b_{ie+1} \Delta Q_{ie+1}^m + c_{ie+1} \Delta Q_{ie+2}^m = d_{ie+1} \quad (2.55)$$

where the coefficients are:

$$a_{ie+1} = \alpha_{ie}$$

$$b_{ie+1} = \delta_{ie}$$

$$c_{ie+1} = 0$$

$$d_{ie+1} = \Delta A_{ie}^m - \gamma_{ie}$$

These coefficients are used to replace the coefficients defined in Eqs. (2.41a) to (2.41d) for the downstream boundary.

#### 2.2.5 Network Boundary Condition

For each river with  $N$  cross sections, there are  $N+1$  unknowns of discharge and  $N-1$  equations (Eq. 2.41). Closing the solution system requires equations from boundary conditions. In addition to the upstream and downstream boundary conditions, the junction of the rivers provides the constraints required to solve the continuity and momentum equations.

A general case is discussed here with  $s$  rivers entering the junction and  $t$  rivers exiting the junction. A total of  $s+t$  boundary conditions exist including one continuity equation and  $s+t-1$  momentum equations. No storage is allowed in the junction. The continuity equation is written as:

$$\sum_{l=1}^s Q_{l,ie+1}^m - \sum_{l=1}^t Q_{l,is}^m = 0 \quad (2.56)$$

where  $Q_{l,ie+1}^m$  is the estimated outlet discharge of river  $l$ ,  $Q_{l,is}^m$  is the estimated entrance discharge of river  $l$ . The correction form of the discharge is written as:

$$\sum_{l=1}^s \Delta Q_{l,ie+1}^m - \sum_{l=1}^t \Delta Q_{l,is}^m = 0 \quad (2.57)$$

A simplified momentum equation is introduced at the junction, requiring that all cross sections associated with the junction share the same water level correction. Assuming river  $t$  is the maximum river index of the rivers that exit the junction, the boundary condition for the river  $l$  entering the junction is written as:

$$\Delta H_{l,ie+1}^m = \Delta H_{t,is}^m \text{ or } \Delta A_{l,ie+1}^m / T_{l,ie+1} = \Delta A_{t,is}^m / T_{t,is} \quad (2.58)$$

The area correction can be replaced by Eq. (2.49), and Eq. (2.58) can be written as:

$$\begin{aligned} (\alpha_{l,ie} \Delta Q_{l,ie}^m + \delta_{l,ie} \Delta Q_{l,ie+1}^m + \gamma_{l,ie}) / T_{l,ie} = \\ (\alpha_{t,is} \Delta Q_{t,is}^m + \delta_{t,is} \Delta Q_{t,is+1}^m + \gamma_{t,is}) / T_{t,is} \end{aligned} \quad (2.59)$$

The same boundary condition for the river  $l$  exiting the junction is written as:

$$\begin{aligned} (\alpha_{l,is} \Delta Q_{l,is}^m + \delta_{l,is} \Delta Q_{l,is+1}^m + \gamma_{l,is}) / T_{l,is} = \\ (\alpha_{t,is} \Delta Q_{t,is}^m + \delta_{t,is} \Delta Q_{t,is+1}^m + \gamma_{t,is}) / T_{t,is} \end{aligned} \quad (2.60)$$

## 2.3 Internal Boundary Condition

Hydraulic structures such as dams, bridges, weirs, and gates may exist along a natural river and special treatments are required in the numerical model. For each internal cross sectional structure, two more unknowns are introduced: the discharge  $Q_i$  and water surface elevation  $Z_i$  at that structure. The conservation of mass serves as one of the equations necessary to solve for the unknowns. The other equation depends upon the particular structure. Structures currently supported by GSTAR-1D are listed in the following sections. Steady and unsteady flow conditions use the same equations, but the interpolation in time of time series data is handled differently. Internal boundary conditions are interpolated using a step function for steady flow simulations and linearly in time for unsteady flow simulations. Internal structures are assumed to occur between cross sections and are identified by the cross section that occurs immediately upstream.

### 2.3.1 Governing Equations for Internal Boundaries

#### 2.3.1.1 Time Stage Table

For this boundary condition, the user enters a known water surface elevation versus time at a cross section. Forexample, this boundary condition could represent a pool that is controlled based upon daily operations:

$$H = H(t) \quad (2.61)$$

### 2.3.1.2 Elevation versus discharge table

For this boundary condition, a user inputs a table of water surface elevation versus flow rate. The water surface elevation for each discharge is linearly interpolated between user-entered points. No extrapolation is performed. This boundary condition could represent many different structures that have a unique relationship between flow rate and water surface elevation:

$$H = H(Q) \quad (2.62)$$

### 2.3.1.3 Weir

To simulate weirs in GSTAR-1D the user enters the spillway crest elevation, the weir width, and the weir coefficient. If the downstream water surface elevation does not impact the upstream water surface elevation, the flow over the weir is considered unsubmerged. The submergence parameter,  $R$ , can be computed as:

$$R = \frac{Z_D - Z_{SP}}{Z_U - Z_{SP}} \quad (2.63)$$

For unsubmerged flow past a weir, discharge is expressed as a function of the water surface elevation,  $Z$ , written as:

$$Q = CB(Z_U - Z_{SP})^{\frac{3}{2}} \quad \text{if } R < 0.67 \quad (2.64)$$

where:  $C$  = weir coefficient;

$Z_{SP}$  = elevation of weir crest;

$Z_U$  is the elevation upstream;

$Z_D$  is the elevation downstream; and

$B$  = width of weir crest.

For submerged flow the flow over the weir is computed as:

$$Q = CBF(Z_D - Z_{SP})(Z_U - Z_D)^{\frac{1}{2}} \quad \text{if } R \geq 0.67 \quad (2.65)$$

where  $F$  is the discharge reduction factor, computed similar to that presented in U.S. Army Corps of Engineers HEC-RAS 3.1 (2002):

$$F = \frac{1}{R_c} - \frac{1}{R_c} \left( \frac{R - R_c}{1 - R_c} \right)^5 \quad (2.66)$$

where  $R_c$  is equal to 0.67. The function in 2.66 ensures that the submerged and unsubmerged results are equivalent at  $R = R_c$  and that  $F = 0$  at  $R = 1$ .

#### 2.3.1.4 Bridge

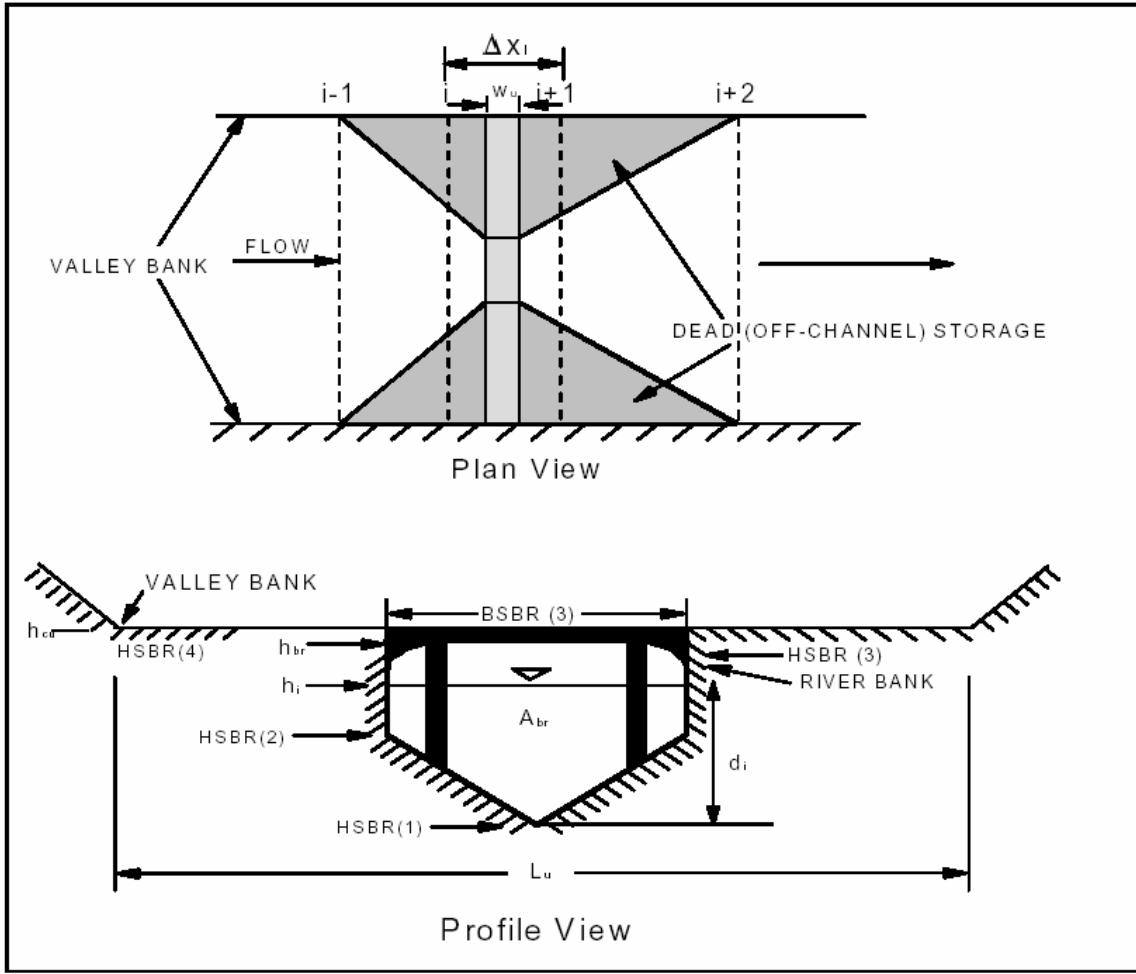


Figure 2.3 Schematic of bridge (Source: Fread and Lewis, 1998)

The present model uses the equations presented in FLDWAV (Fread and Lewis, 1998) for highway/railway bridges and their associated earthen embankments (as shown in Figure 2.3). The discharge can be expressed as:

$$Q = \sqrt{2g} CA_{br} (Z_i - Z_{i+1} + V_i^2 / 2g - \Delta h_f)^{1/2} + cc_u L_u k_u (Z_i - h_{cu})^{3/2} + cc_l L_l k_l (Z_i - h_{cl})^{3/2} \quad (2.67)$$

where:  $k_u = 1.0 \quad \text{if} \quad h_{ru} \leq 0.76 \quad (2.68)$

$$k_u = 1.0 - c_u (h_{ru} - 0.76)^3 \quad \text{if} \quad h_{ru} > 0.76 \quad (2.69)$$

$$c_u = 133(h_{ru} - 0.78) + 10 \quad \text{if} \quad 0.76 < h_{ru} \leq 0.96 \quad (2.70)$$

$$c_u = 400(h_{ru} - 0.96) + 34 \quad \text{if} \quad h_{ru} > 0.96 \quad (2.71)$$

$$h_{ru} = (Z_{i+1} - h_{cu}) / (Z_i - h_{cu}) \quad (2.72)$$

$$cc_u = 3.02(Z_i - h_{cu})^{0.015} \quad \text{if} \quad 0 < h_u \leq 0.15 \quad (2.73)$$

$$cc_u = 3.06 + 0.27(h_u - 0.15) \quad \text{if} \quad h_u > 0.15 \quad (2.74)$$

$$h_u = (Z_i - h_{cu}) / w_u \quad (2.75)$$

$$\Delta h_f = \Delta x_i (Q_{br} / K_i)^2 \quad (2.76)$$

$$Q_{br} = \sqrt{2g} C A_{br} (Z_i - Z_{i+1} + V^2 / 2g)^{1/2} \quad (2.77)$$

$$V = Q_i / A_i \quad (2.78)$$

where:  $C$  = bridge coefficient,

$A_{br}$  = cross-section flow area of the downstream end of bridge opening which is user-specified via a tabular relation of wetted top width versus elevation,

$h_{cu}$  = elevation of the upper embankment crest,

$Z_i$  = water surface elevation at section  $i$  (slightly upstream of bridge),

$Z_{i+1}$  = water surface elevation at section  $i+1$  (slightly downstream of bridge),

$V$  = velocity of flow within the bridge opening,

$L_u$  = length of the upper embankment crest perpendicular to the flow direction including the length of bridge at elevation  $h_{cu}$ ,

$k_u$  = computed submergence correction factor for flow over the upper embankment crest, and

$w_u$  = width (parallel to flow direction) of the crest of the upper embankment.

When the bridge opening is submerged, the coefficient  $C$  in Eqs. (2.67) and (2.77) is replaced by  $C'$  for orifice flow:

$$C' = c_0 C \quad (2.79)$$

where:  $c_0 = \begin{cases} 1.0 - (r - 0.09) & \text{if } 0.09 \leq r \leq 0.31 \\ 1.0 & \text{otherwise} \end{cases} \quad (2.80)$

and:  $r = (Z_i - h_{br}) / d_i \quad (2.81)$

### 2.3.1.5 Radial Gate

For radial gates, GSTAR-1D uses equations similar to those in HEC-RAS 3.0 (Brunner, 2001). The schematic of radial gate is shown in Figure 2.4. According to the upstream and downstream water surface elevations, the flow can be cataloged into three types: free flow, partially submerged flow, and fully submerged flow.

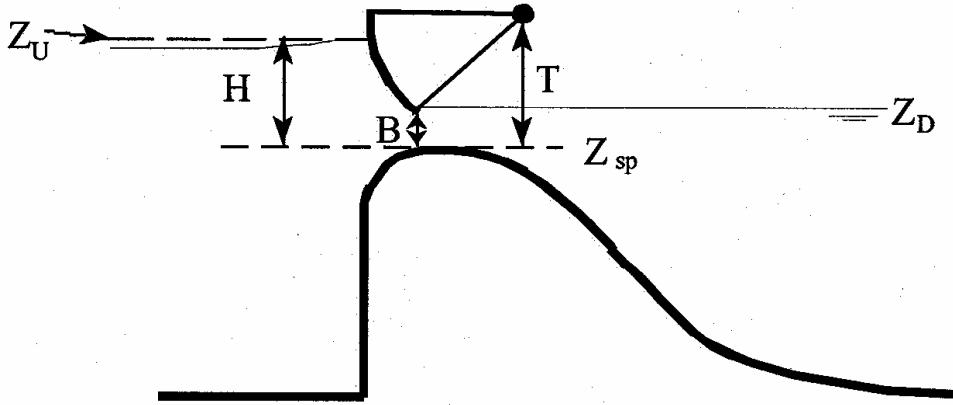


Figure 2.4 Schematic of radial gate (Source: Brunner, 2001)).

When the downstream tailwater elevation ( $Z_D$ ) is not high enough to cause an increase in the upstream headwater elevation, the flow is considered to be “free” flow. The discharge can be expressed as

$$Q = C \sqrt{2g} W T^{TE} B^{BE} H^{HE} \quad \text{if } \frac{Z_D - Z_{SP}}{Z_U - Z_{SP}} \leq 0.67 \quad (2.82)$$

where  $Q$  = flow rate (cfs);  $C$  = discharge coefficient (typically ranges from 0.6 – 0.8);  $W$  = width of the gate (ft);  $T$  = trunnion height (ft, from spillway crest to trunnion pivot point);  $TE$  = trunnion height exponent (typically about 0.16);  $B$  = height of gate opening (ft);  $BE$  = gate opening exponent (typically about 0.72);  $H$  = upstream energy head above the spillway crest ( $Z_U - Z_{SP}$ );  $HE$  = head exponent (typically about 0.62);  $Z_U$  = elevation of the upstream energy grade line (ft);  $Z_D$  = elevation of the downstream water surface (ft);  $Z_{SP}$  = elevation of the spillway crest through the gate (ft).

When the downstream tailwater elevation ( $Z_D$ ) is high enough to cause an increase in the upstream headwater elevation, the flow is considered to be “partially submerged” flow. The discharge can be expressed as

$$Q = C \sqrt{2g} W T^{TE} B^{BE} (3H)^{HE} \quad \text{if } \frac{Z_D - Z_{SP}}{Z_U - Z_{SP}} > 0.67 \quad (2.83)$$

where  $H$  = upstream energy head (ft) above the downstream water surface ( $Z_U - Z_D$ ).

When the discharge is further increased, the gate is “fully submerged” and the discharge can be expressed as

$$Q = CA\sqrt{2gH} \quad \text{if } \frac{Z_D - Z_{SP}}{Z_U - Z_{SP}} > 0.80 \quad (2.84)$$

where  $A$  = area of the gate opening ( $\text{ft}^2$ );  $H$  = upstream energy head (ft) above the downstream water surface ( $Z_U - Z_D$ ), and  $C$  = discharge coefficient (typically 0.8).

### 2.3.2 Implementation for Steady Flows

For an internal boundary, the mass conservation equation is the same as equation (2.12) and the energy equation (2.11) is replaced by the appropriate internal boundary condition. The water surface elevation upstream of the internal boundary is solved using the flow rate computed from the mass conservation equation.

The equation for an internal boundary can be written as:

$$F_i(Y_i, Q_i, Y_{i+1}, Q_{i+1}) = 0 \quad (2.85)$$

This equation is used to replace the energy equation (Eq. 2.11). The derivatives  $\frac{\partial F_i}{\partial Z_i}$ ,  $\frac{\partial F_i}{\partial Q_i}$ ,  $\frac{\partial F_i}{\partial Z_{i+1}}$ , and  $\frac{\partial F_i}{\partial Q_{i+1}}$  are calculated and substituted into Eq. (2.15).

### 2.3.3 Implementation for Unsteady Flows

All internal boundary conditions can be summarized as:

$$Q_i = f(A_{i-1}, A_i) \quad (2.86)$$

where  $A_{i-1}$  and  $A_i$  are the cross section areas before and after the internal boundary, respectively. The discretized form of the internal boundary condition written in iteration form is:

$$\Delta Q_i = -Q_i^n + f(A_{i-1}^n, A_i^n) + \frac{\partial f}{\partial A_{i-1}} \Delta A_{i-1} + \frac{\partial f}{\partial A_i} \Delta A_i \quad (2.87)$$

Expression (2.38) can be used to eliminate unknowns  $\Delta A_{i-1}$  and  $\Delta A_i$  in Eq. (2.87), which results in the following form:

$$a_i \Delta Q_{i-1}^m + b_i \Delta Q_i^m + c_i \Delta Q_{i+1}^m = d_i \quad (2.88)$$

where the coefficients are:

$$\begin{aligned} a_i &= -\frac{\partial f}{\partial A_{i-1}} \alpha_{i-1} \\ b_i &= 1 - \frac{\partial f}{\partial A_{i-1}} \delta_{i-1} - \frac{\partial f}{\partial A_i} \alpha_i \\ c_i &= -\frac{\partial f}{\partial A_i} \delta_i \\ d_i &= f(A_{i-1}^n, A_i^n) - Q_i^n + \frac{\partial f}{\partial A_{i-1}} \gamma_{i-1} + \frac{\partial f}{\partial A_i} \gamma_i \end{aligned}$$

These coefficients are used to replace the coefficients defined in Eqs. (2.41a) to (2.41d).

# 3 Sediment Transport

This chapter describes the methods used to perform the sediment transport calculations. GSTAR-1D simulates the physical processes important to both cohesive and non-cohesive sediment transport. There are three major components of sediment transport:

1. Sediment Routing
2. Bed Material Mixing
3. Cohesive Sediment Consolidation

Sediment routing is the simulation of the downstream movement of sediment in the river flow. Bed material mixing processes include bed material sorting and armoring. Consolidation is compaction of cohesive sediment over time. The modeling of each of these components is described in the following sections.

## 3.1 Sediment Routing

There are two types of sediment routing available in GSTAR-1D: unsteady sediment routing and Exner equation routing. The unsteady sediment routing computes the changes to the suspended sediment concentration with time. The Exner equation routing ignores changes to the suspended sediment concentration over time. Unsteady sediment routing can be used when unsteady flow is being simulated and suspended concentrations change rapidly. In most other cases, Exner equation routing can be used.

### 3.1.1 Exner Equation Routing

The Exner equation (Exner, 1920; 1925) was derived assuming that changes to the volume of sediment in suspension are much smaller than the changes to the volume of sediment in the bed, which is generally true for long-term simulations where steady flow is being simulated. The mass conservation equation for sediment reduces to,

$$\frac{\partial Q_s}{\partial x} + \varepsilon \frac{\partial A_d}{\partial t} - q_s = 0 \quad (3.1)$$

where  $\varepsilon$  = volume of sediment in a unit bed layer volume (one minus porosity);  $A_d$  = volume of bed sediment per unit length;  $Q_s$  = volumetric sediment discharge; and  $q_s$  = lateral sediment inflow per unit length. Integrating (3.1) over a control volume centered on each cross section gives an equation for the deposition depth ( $\Delta Z_b$ ) for a single sediment size fraction at a particular cross section,  $i$ :

$$\varepsilon_i W_i \Delta x_i \Delta Z_{b,i} = q_{s,i} \Delta x_i \Delta t + (Q_{s,i-1} - Q_{s,i}) \Delta t \quad (3.2)$$

where  $W$  is the width of the cross section subject to erosion or deposition. The erosion volumes for each size fraction are summed to compute the total erosion or deposition for a particular cross section. The lateral inflows are user defined and the erosion width is computed based upon the hydraulic calculations. The only

unknowns remaining are the sediment transport rates. The sediment transport rate ( $Q_s$ ) can also be written as  $QC$ , where  $C$  is the computed discharge weighted average sediment concentration. The following sections describe the numerical solution for sediment concentration for the cases of non-cohesive sediment, floodplain routing, and cohesive sediment.

### 3.1.1.2 Non-Cohesive Sediment Routing

If the cross sections are far apart relative it can be acceptable to assume that the bed-material load discharge equals to the sediment transport capacity of the flow; i.e., the bed-material load is transported in an equilibrium mode ( $Q_s = Q_{cap}$ , where  $Q_{cap}$  is the transport capacity). In other words, the exchange of sediment between the bed and the fractions in transport is instantaneous. However, the spatial-delay and/or time-delay effects are important in circumstances where there are rapid hydraulic changes in short reaches. For example, reservoir sedimentation processes and the siltation of estuaries are non-equilibrium processes. Laboratory studies have shown that it may take a significant distance for clear water inflow to reach saturation sediment concentrations. To model these effects, GSTAR-1D uses the analytical solution to the following equation:

$$\frac{dQ_s}{dx} = Q \frac{dC}{dx} = (V_e p - V_d C)W \quad (3.3)$$

where  $V_e$  = erosion velocity, and  $V_d$  = deposition velocity. The analytical solution to the above equation between two cross sections indicated as  $i$  and  $i-1$  is:

$$C_i = C_i^* + (C_{i-1} - C_i^*) \exp\left\{-\frac{V_d \Delta x}{q}\right\} \quad (3.4)$$

where  $C_i^* = V_e p / V_d$  and is the computed sediment transport capacity concentration;  $q$  is the flow per unit width;  $\Delta x$  = reach length; and  $i$  = cross-section index (increasing from upstream to downstream). Eq. (3.4) is employed for each of the particle size fractions in the non-cohesive range, i.e., with a diameter greater than 0.0625 mm. The sediment transport capacity concentration is computed for each size fraction as:

$$C_i^* = p_i C_i^T \quad (3.5)$$

where  $p_i$  = percentage of material of that size fraction in the active layer of the bed; and  $C_i^T$  = sediment transport capacity computed if the bed was composed entirely of that size fraction. The erosion and deposition velocity for non-cohesive sediment are given as:

$$V_e = \min(\alpha w_f, q/L_b) C_i^T \quad \text{and} \quad V_d = \min(\alpha w_f, q/L_b) \quad (3.6)$$

where  $L_b$  is the adaptation length for bed load and the parameter  $\alpha$  is a recovery factor. These parameters control the rate at which the sediment concentration approaches the sediment carrying capacity. Higher values of  $\alpha$  or lower values of  $L_b$  indicate that the concentration reaches the carrying capacity more quickly. The formulation of the adaptation length for bed load is taken from Holly and Rahuel (1990). It is a dimensional value that is usually on the order of large bed features,

such as bars. In GSTAR-1D, separate values for  $\alpha$  are used for deposition versus erosion and the program automatically chooses the correct one. Han and He (1990) recommend a value of 0.25 for deposition and 1.0 for erosion.

The asymptotic behavior of Eq. (3.4) with increasing particle size is shown in Figure 3.1. One can see that as  $d$  (or  $\omega_j$ ) becomes larger  $C_i \rightarrow C_i^*$ .

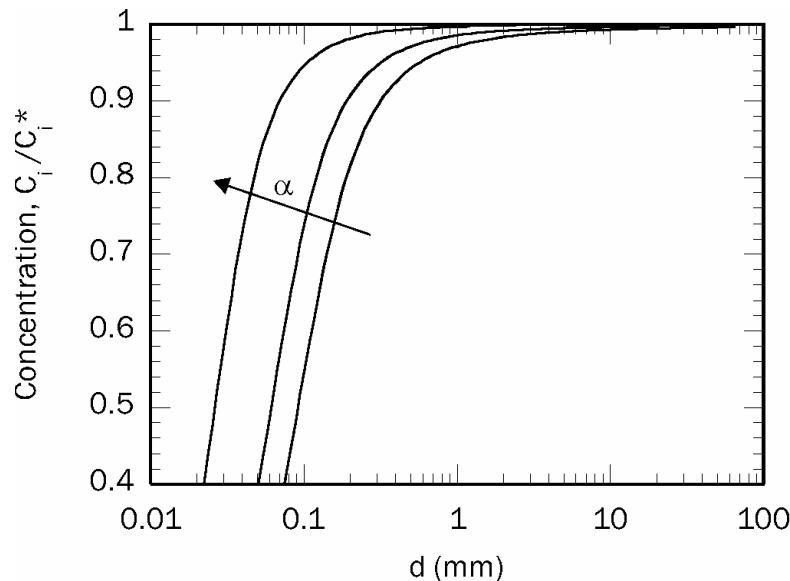


Figure 3.1 Ratio between non-equilibrium concentration and carrying capacity as a function of sediment particle size.

The influence of the recovery parameter  $\alpha$  is illustrated in Figure 3.2. The depositional case represents a situation in which there is a sudden loss of carrying capacity ( $C_i^* = 0$ ) from an upstream equilibrium condition ( $C_{i-1} = C_{i-1}^*$ ). The plot shows the actual normalized concentration for two sizes of the sediment particles. It is clear that the non-equilibrium effect is stronger on the finer particles, and that it diminishes as  $\alpha$  increases. The erosional case represents a sudden increase in carrying capacity, such as when clear water enters a channel with an erodible bed. In this case,  $C_{i-1} = C_{i-1}^* = 0$  and  $C_i^* > 0$ . The same trend occurs as before, i.e., the non-equilibrium effects tend to diminish with increasing particle sizes and recovery factor.

The distance between computational cross sections,  $\Delta x$ , is another important factor in non-equilibrium calculations. Figure 3.3 shows how the non-equilibrium effects vary with distance for the same situations and particle sizes in Figure 3.2. In practice, the values of  $\alpha$  vary widely. If data are available,  $\alpha$  may be a calibration parameter.

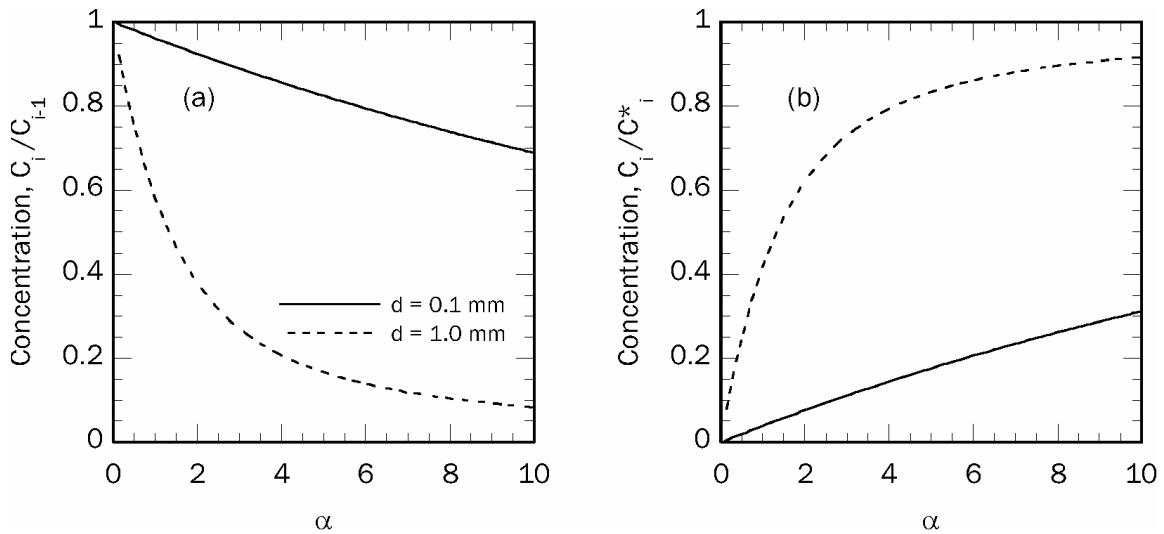


Figure 3.2 Effect of the recovery parameter  $\alpha$  on the computation of non-equilibrium sediment concentrations for two sediment particle sizes. (a) deposition and (b) erosion

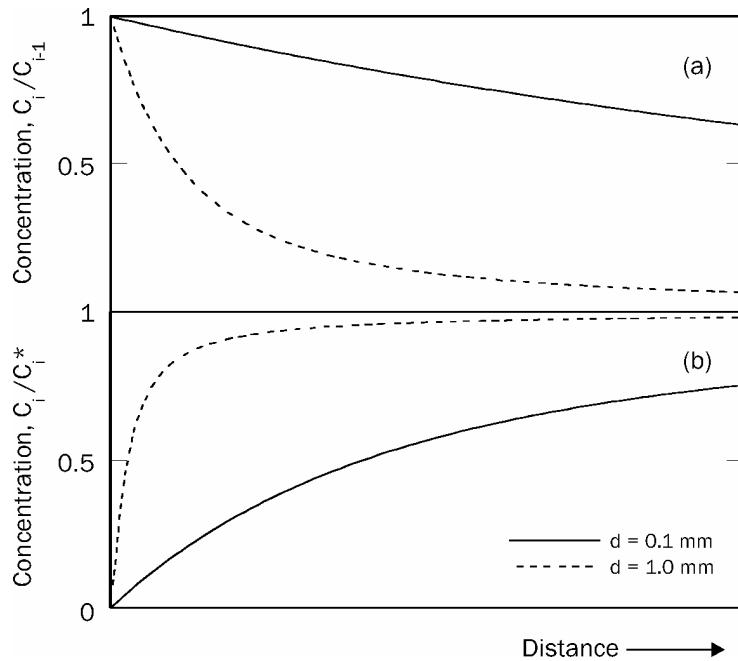


Figure 3.3 Variation of non-equilibrium effects as a function of distance between cross sections for deposition (a) and for erosion (b).

### 3.1.1.3 Floodplain Routing

The user may elect to simulate the exchange of sediment between the main channel and floodplains. The existing 1D non-equilibrium sediment transport model discussed in the previous section is modified to account for the sediment

transfer between the main channel and the floodplains. Because of the high bed roughness and low velocity, the floodplain usually has a lower sediment transport capacity than the main channel for a given sediment size class and usually experiences deposition. To better simulate floodplain deposition, a model is needed to treat floodplain transport separately from main channel transport. In GSTAR-1D, a sub-channel is specified for the left floodplain and another is specified for the right floodplain. The main channel flow is another sub-channel. The definition of the main channel and the floodplains can be based on vegetation and cross-section geometry. The lateral transfer of water and sediment across sub-channels is calculated by the distribution of conveyance across a section. No water is allowed in the floodplain until the water surface is above the bank elevation. When there is no water in the floodplain, the calculations proceed identical to the no floodplain option.

The non-equilibrium sediment mass conservation equation is written for each sub-channel as:

$$Q_{i-1}C_{i-1} - Q_i C_i + (Q_i - Q_{i-1})\tilde{C} + V(C^* - C)W\Delta x = 0 \quad (3.7)$$

where  $\tilde{C}$  = average sediment concentration of lateral flow between the main channel and the floodplain. This is the average sediment concentration in the adjacent sub-channel if there is a net lateral flow into the calculated sub-channel. If there is a net outflow, it is the average sediment concentration in the calculated sub-channel. In Eq. (3.7), the first term is the sediment discharge flowing into the sub-channel reach from upstream. The second term is the sediment discharge flowing out of the sub-channel reach at the downstream end. The third term is the sediment discharge flowing into the sub-channel reach from adjacent sub-channels. The last term is the sediment erosion/deposition term. The differential form of Eq. (3.7) can be written as:

$$\frac{d(QC)}{dx} = (pV_e - V_d C)W + \frac{dQ}{dx}\tilde{C} \quad (3.8)$$

If there is a net flow out of the sub-channel, Eq. (3.8) can be written as:

$$Q \frac{dC}{dx} = (pV_e - V_d C)W \quad (3.9)$$

This equation can be solved analytically assuming constant transport capacity and constant unit width discharge  $Q/T$ , where  $T$  = top width. The average values of  $Q/T$  is used ( $0.5(Q_{i-1}/T_{i-1} + Q_i/T_i)$ ). The sediment concentration at section  $i$  is written as:

$$C_i = C_i^* + (C_{i-1} - C_i^*) \exp\left\{-\frac{V_d \Delta x W}{Q}\right\} \quad (3.10)$$

The concentration of sediment transferred between two sub-channels is computed as the weighted average concentration in the sub-channel where there is net outflow:

$$\tilde{C} = \frac{Q_{i-1}C_{i-1} + Q_i C_i}{Q_{i-1} + Q_i} \quad (3.11)$$

If there is a net flow into the sub-channel, Eq. (3.8) can be written as:

$$\frac{dC}{dx} + P(x)C = S(x) \quad (3.12)$$

where  $P(x)$  and  $S(x)$  are defined as:

$$P(x) = \frac{V_d W}{Q} + \frac{1}{Q} \frac{dQ}{dx} \quad (3.13)$$

$$S(x) = \frac{V_d W}{Q} C^* + \frac{1}{Q} \frac{dQ}{dx} \tilde{C} \quad (3.14)$$

The solution of Eq. (3.8) can be written as:

$$C(x) = C_0 \exp[-\xi(x)] + \exp[-\xi(x)] \int_{x_{i-1}}^{x_i} \exp[\xi(x)] S(x) dx \quad (3.15)$$

$$\text{where: } \xi(x) = \int_0^x P(x) dx = \frac{V_d W}{Q} x + \ln(\frac{Q_i}{Q_{i-1}}) \quad (3.16)$$

By substituting Eqs. (3.14) and (3.16) into Eq. (3.15) and using the same assumption of constant transport capacity through the reach, the final solution for Eq. (3.15) can be written as:

$$C_i = C_i^* + (C_{i-1} \frac{Q_{i-1}}{Q_i} - C_{i-1}^*) \exp\left(-\frac{V_d W \Delta x}{Q}\right) + (Q_i - Q_{i-1}) \tilde{C} \frac{Q}{V_d W \Delta x} \left[1 - \exp\left(-\frac{V_d W \Delta x}{Q}\right)\right] \quad (3.17)$$

### 3.1.1.4 Cohesive Sediment

GSTAR-1D defines cohesive sediment as sediment with a diameter smaller than 0.0625 mm. For cohesive sediment, the capacity concentration,  $C^*$ , is not defined because the capacity concentration is essentially controlled by the erosion or deposition rates occurring in the river. In GSTAR-1D, the erosion of fine sediment is prevented only if the volumetric concentration exceeds 20% by volume (approximately 530,000 mg/l).

The steady sediment transport equation for cohesive sediment is written as

$$\frac{dQ_s}{dx} = (V_e P - V_d C)W + \frac{dQ}{dx} \tilde{C} \quad (3.18)$$

where  $V_e$  and  $V_d$  = cohesive sediment erosion and deposition velocities, respectively;  $P$  = volume fraction of cohesive sediment in the active layer;  $C$  = cohesive sediment volumetric concentration. The computation of the erosional and depositional velocities is given in Section 3.1.5 to Section 3.1.7. If the erosion velocity is zero, and the deposition velocity is greater than zero, the solution to (3.18) is given as:

$$C_i = C_{i-1} \exp\left(-\frac{V_d W \Delta x}{Q}\right) + \frac{\Delta Q}{Q} \tilde{C} \quad (3.19)$$

If the deposition velocity is zero and the erosion velocity is greater than zero, the solution to (3.18) is given as:

$$C_i = C_{i-1} + \frac{V_e P W \Delta x}{Q} + \frac{\Delta Q}{Q} \tilde{C} \quad (3.20)$$

### 3.1.2 Unsteady Sediment Transport

When simulating unsteady flow, the changes in suspended concentration cannot always be ignored. To compute the changes in suspended sediment concentration, the convection-diffusion equation with a source term for sediment erosion/deposition is used. If floodplains are being simulated, the sediment transport is two-dimensional (2D) and the cross-stream component of sediment transport in the  $y$ -direction is responsible for the transfer of sediment into and out of the floodplain. If floodplains are not simulated, the transport in the  $y$ -direction is ignored. The 2D depth-averaged convection-diffusion equation for a particular sediment size class is:

$$\frac{\partial(hC)}{\partial t} + \frac{\partial(huC)}{\partial x} + \frac{\partial(hvC)}{\partial y} = \frac{\partial}{\partial x}(D_x h \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(D_y h \frac{\partial C}{\partial y}) + \Omega \quad (3.21)$$

where  $h$  = depth;  $C$  = depth-averaged sediment concentration of one constituent;  $t$  = time;  $u, v$  = depth-averaged velocity components in the horizontal streamwise and transverse directions,  $x$  and  $y$ , respectively;  $D_x, D_y$  = diffusion coefficients in the  $x$  and  $y$  directions, respectively; and  $\Omega$  = source (erosion) and sink (deposition) terms for one sediment constituent. The source term can be written as:

$$\Omega = V_e P - V_d C \quad (3.22)$$

where  $V_e, V_d$  = erosion and deposition velocities, respectively;  $P_a$  = sediment fraction of the calculated constituent in the active layer. The erosion and deposition velocities are defined in Section 3.1.4 for non-cohesive sediment and in Sections 3.1.5 to 3.1.7 for cohesive sediment.

One obtains the conservation equation by integrating Eq. (3.21) over a control volume:

$$\frac{\partial}{\partial t} \iint_A Ch dA + \int_l C(h \vec{V} \cdot \vec{n}) dl = \int_l Dh(\nabla C \cdot \vec{n}) dl + \iint_A \Omega dA \quad (3.23)$$

This equation is applied to each computational cell in Figure 3.4. Lower case letters denote the cell boundary lines (CL) and their directions (e, w, n, and s) with respect to cell central (P), and upper case letters denote the control surface (CS) centers and their directions (E, W, N, and S). Eq. (3.21) is solved with a split operator, meaning that the convective and diffusive terms are solved separately from the source term. This is to maintain stability and to maintain consistency with the methods used to compute the source term in the Exner Equation routing methods.

A general discrete approximation of the convective and diffusion terms in Eq. (3.23) can be written for each cell as:

$$A_P C_P + \sum A_L C_L = R_P \quad (3.24)$$

where  $P$  represents the CS center, and  $L$  is summed over the neighborhood CS centers W, E, S, or N as shown in Figure 3.4.

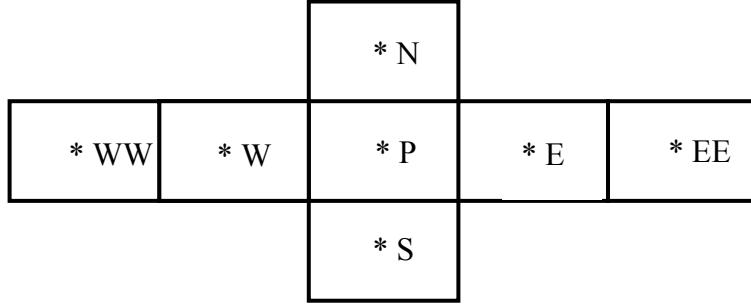


Figure 3.4 Discrete grid for unsteady flow simulation

The following sections discuss the integrals in Eq. (3.23) and their contributions to the coefficients and source terms in Eq. (3.24).

### 3.1.2.2 Unsteady Term

The unsteady term requires integration over the CS area. The implicit Euler method is applied for time marching. The unsteady term is approximated by the product of CS area and the  $ch$  value at the CS center,

$$\frac{\partial}{\partial t} \iint_A Ch dA = \frac{\Delta C_P}{\Delta t} h_P a_P \quad (3.25)$$

where  $\Delta C_P = C_p^n - C_p^{n-1}$ , and the superscripts  $n-1$  and  $n$  denote the previous and current time steps, respectively. The unsteady term contributions to the coefficients in Eq. (3.24) and can be written as:

$$A_P|_U = \frac{h_P a_P}{\Delta t} \quad (3.26)$$

where the subscript  $U$  indicates the contribution of the unsteady term to the  $A_P$  coefficient;  $\Delta t$  = time step;  $h_P$  = average depth of CS; and  $a_P$  = area of CS.

### 3.1.2.3 Convective Term

The Lax-Wendroff TVD (Total Variation Diminishing) Method is used to discretize the convective term. The original Lax-Wendroff Method is a second-order accuracy scheme. However, numerical results oscillate on discontinuities. The Lax-Wendroff TVD Method suppresses the correction term in Lax-Wendroff Method when discontinuities appear. The TVD scheme remains second-order accurate for smooth regions but becomes a first order scheme near discontinuities to avoid oscillations. Details of Lax-Wendroff TVD Method are discussed in Tannehill et al. (1997).

Approximations of the convective term involve values of variables at the CL centers:

$$\int_l c(h\vec{V} \cdot \vec{n})dl = F_e^* \Delta l_e - F_w^* \Delta l_w + F_n^* \Delta l_n - F_s^* \Delta l_s \quad (3.27)$$

where  $h\vec{V} \cdot \vec{n}$  = mass flux through cell boundaries,  $\Delta l_e$  = length of east boundary of CS; and  $F = C(h\vec{V} \cdot \vec{n})$ . In Lax-Wendroff TVD method,  $F_e^*$  can be expressed as

$$F_e^* = \frac{1}{2} [h_e V_e C_P + h_e V_e C_E - h_e W_e (C_E - C_P)] \quad (3.28)$$

where

$$W_e = |V_e| [(1 - \psi) + \psi c_r |V_e|]$$

and  $\psi$  is the flux limiter computed as,

$$\psi = \max[0, \min(2, 2r, (1+r)/2)], r = \frac{C_E - C_P}{C_{i1} - C_{i2}} \quad (3.29)$$

with  $i_1 = P$  and  $i_2 = W$  if  $V_e$  is positive and  $i_1 = EE$  and  $i_2 = E$  if  $V_e$  is negative. Eq. (3.29) is van Leer's MUSCL flux limiter (van Leer, 1979). If  $\psi = 1$  then the 2<sup>nd</sup> order accurate Lax-Wendroff scheme is obtained. If  $\psi = 0$  then the scheme is a first order accurate upwind scheme. The Crank-Nicolson method is applied to get second-order accuracy in time but it is conditionally stable. With this scheme,  $F_e^* \Delta l_e$  can be expressed as

$$\begin{aligned} F_e^* \Delta l_e &= \left( \frac{1}{2} Q_e + \frac{1}{2} h_e \Delta l_e W_e \right) C_P + \left( \frac{1}{2} Q_e - \frac{1}{2} h_e \Delta l_e W_e \right) C_E \\ &= \left( \frac{1}{2} Q_e + \frac{1}{2} a_e W_e \right) (C_P^{n-1} + \theta \Delta C_p) \\ &\quad + \left( \frac{1}{2} Q_e - \frac{1}{2} a_e W_e \right) (C_E^{n-1} + \theta \Delta C_E) \end{aligned} \quad (3.30)$$

where  $Q_e$  = the flow rate through the east side of CS,  $a_e = h_e \Delta l_e$  the area of the east side of CS,  $\theta$  = implicit factor ( $0 < \theta < 1$ ). If unconditional stability is to be guaranteed, then  $\theta$  should be greater than 0.5. Similar expressions can be written for the other three terms in Eq. (3.27). The final contributions of the convective term to the coefficients in Eq. (3.24) can be written as:

$$\begin{aligned}
A_E|_C &= \theta \left( \frac{1}{2} Q_e - \frac{1}{2} a_e W_e \right) \\
A_W|_C &= \theta \left( -\frac{1}{2} Q_w - \frac{1}{2} a_w W_w \right) \\
A_N|_C &= \theta \left( \frac{1}{2} Q_n - \frac{1}{2} a_n W_n \right) \\
A_S|_C &= \theta \left( -\frac{1}{2} Q_s - \frac{1}{2} a_s W_s \right) \\
A_P|_C &= \theta \left( \frac{1}{2} Q_e + \frac{1}{2} a_e W_e \right)_e + \theta \left( -\frac{1}{2} Q_w + \frac{1}{2} a_w W_w \right) \\
&\quad + \theta \left( \frac{1}{2} Q_n + \frac{1}{2} a_n W_n \right)_n + \theta \left( -\frac{1}{2} Q_s + \frac{1}{2} a_s W_s \right)_s \\
R|_C &= -\frac{1}{\theta} \left( \begin{array}{l} A_P|_C C_P^{n-1} + A_E|_C C_E^{n-1} + A_W|_C C_W^{n-1} + \\ A_N|_C C_N^{n-1} + A_S|_C C_S^{n-1} \end{array} \right)
\end{aligned} \tag{3.31}$$

where the subscript  $C$  indicates the contribution of the convective term to the coefficients of Eq. (3.24).

### 3.1.2.4 Diffusion Term

The approximation of the diffusion term in Eq. (3.21) also involves the values of variables at the CL. First, the central differential scheme (CDS) is applied in space, and then the Crank-Nicolson method is applied in time. The discretization of the diffusion term is second-order accurate in both space and time.

$$\begin{aligned}
-\int_I Dh(\nabla c \cdot \vec{n}) dl &= -D_e a_e \frac{C_E - C_P}{\Delta x_e} + D_w a_w \frac{C_P - C_W}{\Delta x_w} \\
&\quad - D_n a_n \frac{C_N - C_P}{\Delta x_n} + D_s a_s \frac{C_P - C_S}{\Delta x_s} \\
&= -D_e a_e \frac{C_E^{n-1} + \theta \Delta C_E - C_P^{n-1} - \theta \Delta C_P}{\Delta x_e} + D_w a_w \frac{C_P^{n-1} + \theta \Delta C_P - C_W^{n-1} - \theta \Delta C_W}{\Delta x_w} \\
&\quad - D_n a_n \frac{C_N^{n-1} + \theta \Delta C_N - C_P^{n-1} - \theta \Delta C_P}{\Delta x_n} + D_s a_s \frac{C_P^{n-1} + \theta \Delta C_P - C_S^{n-1} - \theta \Delta C_S}{\Delta x_s}
\end{aligned} \tag{3.32}$$

where  $\Delta x_e$ ,  $\Delta x_w$ ,  $\Delta x_s$ , and  $\Delta x_n$  are distances between the CS center P and neighborhood CS centers E, W, N, and S, respectively. The coefficients from the diffusion term can now be summarized as:

$$\begin{aligned}
A_E|_D &= -\theta D_e a_e / \Delta x_e \\
A_W|_D &= -\theta D_w a_w / \Delta x_w \\
A_N|_D &= -\theta D_n a_n / \Delta x_n \\
A_S|_D &= -\theta D_s a_s / \Delta x_s \\
A_P|_D &= -(A_E|_D + A_W|_D + A_N|_D + A_S|_D) \\
R|_D &= -\frac{1}{\theta} \left( \begin{array}{l} A_P|_D C_P^{n-1} + A_E|_D C_E^{n-1} + A_W|_D C_W^{n-1} + \\ A_N|_D C_N^{n-1} + A_S|_D C_S^{n-1} \end{array} \right)
\end{aligned} \tag{3.33}$$

where the subscript  $D$  indicates the contribution of the diffusion term to the coefficients of Eq. (3.24)

### 3.1.2.5 Discretized Sediment Transport Equation

Adding all the convective and diffusive terms gives:

$$A_P C_P + \sum A_L C_L = R \quad (3.34)$$

where  $P$  = CS center;  $L$  = neighborhood CS centers  $W$ ,  $E$ ,  $S$ , or  $N$ , respectively; and:

$$\begin{aligned} A_P &= A_P|_U + A_P|_C + A_P|_D \\ A_L &= A_L|_C + A_L|_D \\ R &= R|_C + R|_D \end{aligned} \quad (3.35)$$

For multiple sub-channels, Eq. (3.35) is solved by a 5-point 2D equation solver. If there is only one sub-channel, the sediment transport solution is simplified as a 1D problem and Eq. (3.35) is solved by a 3-point 1D equation solver.

### 3.1.2.6 Source Terms

The only term remaining in the sediment transport Eq. (3.23) is the source term from net sediment erosion and deposition in the streamwise direction. The source term is calculated using a split operator approach. For each time step, the matrix equation that includes the convective and diffusive terms (3.24) is solved first, then the concentrations are updated by calculating the source term as follows. For non-cohesive sediment, the concentration is computed as:

$$C_i = C_i^* + (\hat{C}_i - C_i^*) \exp\left\{-\frac{V_d \Delta t}{h}\right\} \quad (3.36)$$

where  $\hat{C}_i$  is the concentration computed after Eq. (3.24) is solved,  $\Delta t$  is the time step, and  $h$  is the average flow depth. For cohesive sediment, if the erosion velocity is zero, and the deposition velocity is greater than zero, the concentration is computed as:

$$C_i = \hat{C}_i \exp\left(-\frac{V_d \Delta t}{h}\right) \quad (3.37)$$

If, for cohesive sediment, the deposition velocity is zero and the erosion velocity is greater than zero, the solution to (3.18) is given as:

$$C_i = C_{i-1} + \frac{V_e P \Delta t}{h} \quad (3.38)$$

The average depth of deposition for each size fraction at a cross section  $i$  is calculated using mass conservation as:

$$\varepsilon_i W_i \Delta x \Delta Z_{b,i} = (C_i^n - \hat{C}_i) A_i \Delta x \quad (3.39)$$

where  $A_i$  is the cross sectional area. The erosion volumes for each size fraction are summed to compute the total erosion or deposition for a particular cross section.

### 3.1.3 Non-Cohesive Particle Fall Velocity Calculations

Computation of particle fall velocity is necessary for several non-cohesive sediment transport capacity calculations. GSTAR-1D computes sediment fall velocities in different ways, depending on the sediment transport equation used and on particle size. When Toffaleti's equation is used, Rubey's formula (Rubey, 1933) is employed:

$$\omega_f = F \sqrt{dg(G-1)} \quad (3.40)$$

where

$$F = \left[ \frac{2}{3} + \frac{36v^2}{gd^3(G-1)} \right]^{1/2} - \left[ \frac{36v^2}{gd^3(G-1)} \right]^{1/2} \quad (3.41)$$

for particles with diameter,  $d$ , between 0.0625 mm and 1 mm. For particles greater than 1 mm,  $F = 0.79$ . In the above equations,  $\omega_f$  = fall velocity of sediments;  $g$  = acceleration due to gravity;  $G$  = specific gravity of sediments; and  $v$  = kinematic viscosity of water. In GSTAR-1D, the specific gravity of sediments is 2.65 (quartz) and the viscosity of water is computed from the water temperature,  $T$ , using the following expression:

$$v = \frac{1.792 \times 10^{-6}}{1.0 + 0.0337T + 0.000221T^2} \quad (3.42)$$

with  $T$  in degrees Centigrade and  $v$  in  $m^2/s$ .

When any of the other sediment transport formulas are used, values recommended by the U.S. Interagency Committee on Water Resources Subcommittee on Sedimentation (1957) are used (Figure 3.5). GSTAR-1D assumes the Corey shape factor of  $SF = 0.7$ , which is defined as

$$SF = \frac{c}{\sqrt{ab}} \quad (3.43)$$

where  $a$ ,  $b$ , and  $c$  = the length of the longest, the intermediate, and the shortest mutually perpendicular axes of the particle, respectively. For particles with diameters above the range given in Figure 3.5, i.e. greater than 10 mm, the following formula is used:

$$\omega_f = 1.1 \sqrt{(G-1)gd} \quad (3.44)$$

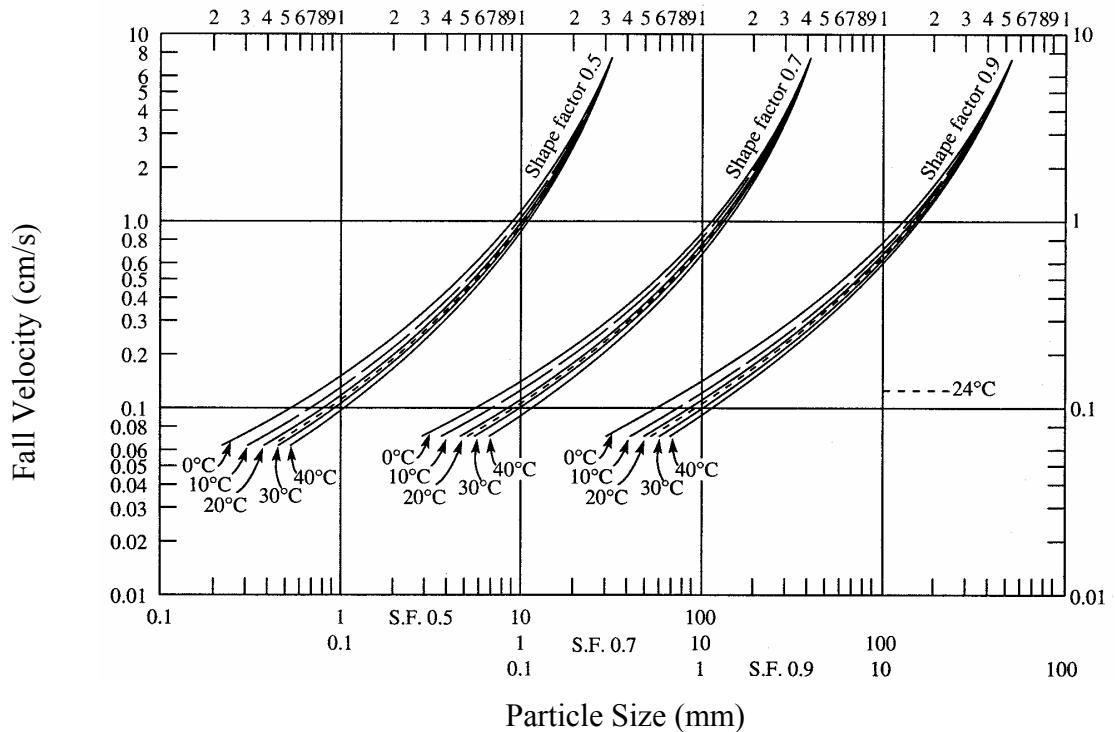


Figure 3.5 Relation between particle sieve diameter and its fall velocity according to the U.S. Interagency Committee on Water Resources Subcommittee on Sedimentation (1957)

### 3.1.4 Non-Cohesive Sediment Transport Capacity

The literature contains many sediment transport functions. Usually, each transport function was developed for a certain range of sediment size and flow conditions. Computed results based on different transport functions can differ significantly from each other and from measurements. No universal function exists which can be applied with accuracy to all sediment and flow conditions. With the exception of Yang's formulas, most transport functions are intended for subcritical flows. GSTAR-1D employs 13 transport functions for non-cohesive material, presented in Table 3.1. Yang (1996) published a more detailed description of some of these functions including comprehensive comparisons and evaluations. New transport formulas are often added to the code as they are developed. It is recommended that user's frequently check for the most recent version of the code on the Reclamation web site.

Table 3.1 Sediment transport functions available in GSTAR-1D and its type (B = bed load; BM = bed-material total load)

Equations	Type
DuBoys (1879)	B
Meyer-Peter and Müller (1948)	B
Laursen (1958)	BM
Modified Laursen's Formula (Madden, 1993)	BM
Toffaleti (1969)	BM
Engelund and Hansen (1972)	BM
Ackers and White (1973)	BM
Ackers and White (HR Wallingford, 1990)	BM
Yang (1973) + Yang (1984)	BM
Yang (1979) + Yang (1984)	BM
Parker (1990)	B
Brownlie (1981)	BM
Yang et al. (1996)	BM

### 3.1.4.1 DuBoys' Method (1879)

The work of DuBoys (1879) is based on the premise that the sediment moves in layers that slide over each other. Although the concept was not entirely correct, the equation can still be used to reasonably describe the relationship between shear stress and bed load transport. DuBoys developed an expression based on excess shear stress:

$$q_b = K\tau(\tau - \tau_c) \quad (3.45)$$

where  $q_b$  = bed load discharge by volume per unit channel width ( $\text{ft}^2/\text{s}$ );  $\tau$  = bed shear stress ( $\text{lb}/\text{ft}^2$ ); and  $\tau_c$  = critical tractive force along the bed.  $\tau_c$  can be computed from Shields diagram. Straub (1935) found the following relationship for  $K$ :

$$K = \frac{0.173}{d^{3/4}} \quad (3.46)$$

where  $d$  = particle size in mm.

### 3.1.4.2 Meyer-Peter and Müller's Formula (1948)

In non-dimension form, the Meyer-Peter and Müller's bedload formula (1948) is:

$$q_b^{2/3} \left( \frac{\gamma}{g} \right)^{1/3} \frac{0.25}{(\gamma_s - \gamma)d} = \frac{(K_s / K_r)^{3/2} \gamma RS}{(\gamma_s - \gamma)d} - 0.047 \quad (3.47)$$

where  $\gamma$  and  $\gamma_s$  = specific weights of water and sediment, respectively;  $R$  = hydraulic radius;  $S$  = energy slope;  $d$  = mean particle diameter;  $\rho$  = specific mass of water;  $q_b$  = bedload rate in underwater weight per unit time and width; and  $(K_s/K_r)S$  = the adjusted energy slope that is responsible for bed-load motion. The value of  $K_s$  and  $K_r$  can be computed from:

$$K_s = \frac{V}{C_m R^{2/3} S^{1/2}} \quad (3.48)$$

and

$$K_r = \frac{26}{d_{90}^{1/6}} \quad (3.49)$$

where  $d_{90}$  = the size of sediment for which 90 percent of the material is finer and is in meters.

### **3.1.4.3 Laursen's Formula (1958) and Modified Version (Madden, 1993)**

Laursen's formula (1958) was expressed in dimensionally homogeneous forms by an American Society of Civil Engineers Task Committee (1971) as,

$$C_t = 0.01\gamma \sum_i p_i \left( \frac{d_i}{D} \right)^{7/6} \left( \frac{\tau'}{\tau_{ci}} - 1 \right) f \left( \frac{U^*}{\omega_i} \right) \quad (3.50)$$

where  $C_t$  = sediment concentration by weight per unit volume;  $U^* = \sqrt{gDS}$ ;  $p_i$  = percentage of materials available in size fraction  $i$ ;  $\omega_i$  = fall velocity of particles of mean size  $d_i$  in water;  $D$  = average water depth; and  $\tau_{ci}$  = critical tractive force for sediment size  $d_i$  as given by the Shields diagram. Laursen's bed shear stress,  $\tau'$ , caused by grain resistance resulting from the use of the Manning equation is,

$$\tau' = \frac{\rho V^2}{58} \left( \frac{d_{50}}{D} \right)^{1/3} \quad (3.51)$$

In Eq. (3.50), the parameter  $\tau'/\tau_{ci} - 1$  is important in determining bed load, and the parameter  $U^*/\omega_i$  relates to suspended load. The functional relation  $f(U^*/\omega_i)$  is given by Laursen (1958) in a graphical form.

Madden (1993) revised the Laursen relation to fit the sediment load discharge rating curves in the lower Arkansas River. The result was a curve parallel to the original one, but one that predicts significantly higher transport rates. Both the original Laursen equation and the revised equation by Madden are implemented in GSTAR-1D.

### **3.1.4.4 Toffaleti's Method (1969)**

Toffaleti's method (1969) is based on the concept of Einstein (1950) and Einstein and Chen (1953) with the following simplifications: (1) channel width for sediment discharge is equal to that of a rectangular channel of width  $B$  and depth  $R$ , with  $R$  being the hydraulic radius of the actual channel; and (2) the total depth of flow is divided into four zones. The bed material load,  $Q_{ti}$ , for sediment of size  $d_i$  is

$$Q_{ti} = B(q_{bi} + q_{sui} + q_{smi} + q_{sli}) \quad (3.52)$$

where  $B$  = channel width; and  $q_{bi}$ ,  $q_{sui}$ ,  $q_{smi}$ ,  $q_{sli}$  = sediment load per unit width in the bed zone, upper zone, middle zone, and lower zone, respectively. Semi-

empirical and graphical methods were used by Toffaleti for the computation of sediment load in each zone.

### **3.1.4.5 Engelund and Hansen's Method (1972)**

Engelund and Hansen (1972) proposed the following transport function:

$$f' \phi = 0.1\theta^{5/2} \quad (3.53)$$

$$f' = \frac{2gSD}{V^2} \quad (3.54)$$

$$\phi = \frac{q_t}{\gamma_s} \left[ \frac{\gamma_s - \gamma}{\gamma} gd^3 \right]^{-1/2} \quad (3.55)$$

$$\theta = \frac{\tau}{(\gamma_s - \gamma)d} \quad (3.56)$$

where  $g$  = gravitational acceleration;  $S$  = energy slope;  $V$  = average flow velocity;  $q_t$  = total sediment discharge by weight per unit width;  $\gamma_s$  and  $\gamma$  = specific weights of sediment and water, respectively;  $d$  = median particle diameter;  $D$  = mean water depth; and  $\tau$  = shear stress along the bed.

### **3.1.4.6 Ackers and White's Method (1973) and (HR Wallingford, 1990)**

Ackers and White (1973) applied dimensional analysis to express the mobility and transport rate of sediment in terms of dimensionless parameters. Their mobility number for sediment is

$$F_{gr} = U^{*n} \left[ gd \left( \frac{\gamma_s}{\gamma} - 1 \right) \right]^{-1/2} \left[ \frac{V}{\sqrt{32} \log(\alpha D/d)} \right]^{1-n} \quad (3.57)$$

where  $U^*$  = shear velocity;  $n$  = transition exponent, depending on sediment size;  $\alpha = 10$ , in turbulent flow;  $d$  = sediment particle size; and  $D$  = water depth. They also expressed the sediment size by a dimensionless grain diameter:

$$d_{gr} = d \left[ \frac{g}{\nu^2} \left( \frac{\gamma_s}{\gamma} - 1 \right) \right]^{1/3} \quad (3.58)$$

where  $\nu$  = kinematic viscosity of water. A dimensionless sediment transport function can then be expressed as

$$G_{gr} = f(F_{gr}, d_{gr}) \quad (3.59)$$

with

$$G_{gr} = \frac{XD}{(d\gamma_s)/\gamma} \left( \frac{U^*}{V} \right)^n \quad (3.60)$$

where  $X$  = rate of sediment transport in terms of mass flow per unit mass flow rate, i.e., concentration by weight of fluid flux. The generalized dimensionless sediment transport function can also be expressed as

$$G_{gr} = C \left( \frac{F_{gr}}{A} - 1 \right)^m \quad (3.61)$$

The values of  $A$ ,  $C$ ,  $m$ , and  $n$  were determined by Ackers and White (1973) based on best-fit curves of laboratory data with sediment sizes greater than 0.04 mm and Froude numbers less than 0.8.

The original Ackers and White formula is known to overpredict transport rates for fine sediments (smaller than 0.2 mm) and for relatively coarse sediments. To correct that tendency, a revised form of the coefficients was published (HR Wallingford, 1990). Both versions of the coefficients are implemented in GSTAR-1D. Table 3.2 compares the original and the revised coefficients.

Table 3.2 Coefficients for the 1973 and 1990 versions of the Ackers and White formula

	<b>1973</b>	<b>1990</b>
$1 < d_{gr} \leq 60$	$A = 0.23d_{gr}^{-1/2} + 0.14$ $\log C = -3.53 + 2.86 \log d_{gr}$ $-(\log d_{gr})^2$ $m = 9.66d_{gr}^{-1} + 1.34$ $n = 1.00 - 0.56 \log d_{gr}$	$A = 0.23d_{gr}^{-1/2} + 0.14$ $\log C = -3.46 + 2.79 \log d_{gr}$ $-0.98(\log d_{gr})^2$ $m = 6.83d_{gr}^{-1} + 1.67$ $n = 1.00 - 0.56 \log d_{gr}$
$d_{gr} > 60$	$A = 0.17$ $C = 0.025$ $m = 1.50$ $n = 0$	$A = 0.17$ $C = 0.025$ $m = 1.78$ $n = 0$

### 3.1.4.7 Yang's Sand (1973) and Gravel (1984) Transport Formulas

Yang's 1973 dimensionless unit stream power formula for sand transport is

$$\begin{aligned} \log C_{ts} = & 5.435 - 0.286 \log \frac{\omega d}{v} - 0.457 \log \frac{U^*}{\omega} \\ & + \left( 1.799 - 0.409 \log \frac{\omega d}{v} - 0.314 \log \frac{U^*}{\omega} \right) \log \left( \frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right) \end{aligned} \quad (3.62)$$

where  $C_{ts}$  = total sand concentration in parts per million by weight;  $\omega$  = sediment fall velocity;  $d$  = sediment particle diameter;  $v$  = kinematic viscosity of water;  $U^*$  = shear velocity;  $VS$  = unit stream power;  $V$  = average flow velocity;  $S$  = water surface or energy slope; and  $V_{cr}$  = critical average flow velocity at incipient motion. The coefficients in Eq. (3.62) were determined from 463 sets of laboratory flume data. Eq. (3.62) applies to sand transport with particle diameters less than 2 mm.

The critical dimensionless unit stream power,  $V_{cr}S/\omega$ , is the product of dimensionless critical velocity  $V_{cr}/\omega$  and energy slope  $S$ , where

$$\frac{V_{cr}}{\omega} = \begin{cases} \frac{2.5}{\log(U^*d/v) - 0.06} + 0.66 & \text{if } 1.2 < \frac{U^*d}{v} < 70 \\ 2.05 & \text{if } 70 \leq \frac{U^*d}{v} \end{cases} \quad (3.63)$$

Yang's 1984 dimensionless unit stream power formula for gravel transport with particle diameters equal to or greater than 2 mm is

$$\begin{aligned} \log C_{tg} = & 6.681 - 0.633 \log \frac{\omega d}{v} - 4.816 \log \frac{U^*}{\omega} \\ & + \left( 2.784 - 0.305 \log \frac{\omega d}{v} - 0.282 \log \frac{U^*}{\omega} \right) \\ & \log \left( \frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right) \end{aligned} \quad (3.64)$$

where  $C_{tg}$  = total gravel concentration in parts per million by weight. The coefficients in Eq. (3.64) were determined from 167 sets of laboratory flume data.

The incipient motion criteria given in Eq. (3.63) should be used for Eqs. (3.62) and (3.64). Because of the range of data used for the determination of the coefficients in Eq. (3.64), the equation should be applied to gravel with median particle size between 2 and 10 mm. However, published literature suggests that Eq. (3.64) may be applicable to materials coarser than 10 mm. GSTAR-1D uses Eq. (3.64) for sizes up to 100 mm. Eqs. (3.62) and (3.64) were originally derived for uniform materials. When they are applied to nonuniform materials, the total sediment concentration should be computed using Eq. (3.5).

For natural rivers, the bed-material size may vary from sand to gravel. In this case, GSTAR-1D uses Eqs.(3.62) for the sand sized sediment and (3.64) for the gravel sized sediment.

### 3.1.4.8 Yang's Sand (1979) Transport Formulas

Yang (1979) proposed a sand transport formula for flow conditions well exceeding those required for incipient motion. In this case, the dimensionless critical unit stream power required at incipient motion can be neglected. Yang's 1979 sand transport formula for sediment concentration greater than 100 parts per million by weight is

$$\begin{aligned} \log C_{ts} = & 5.165 - 0.153 \log \frac{\omega d}{v} - 0.297 \log \frac{U^*}{\omega} \\ & + \left( 1.780 - 0.360 \log \frac{\omega d}{v} - 0.480 \log \frac{U^*}{\omega} \right) \log \frac{VS}{\omega} \end{aligned} \quad (3.65)$$

The coefficients in Eq. (3.65) were determined from 452 sets of laboratory flume data. Eqs. (3.62) and (3.65) give about the same degree of accuracy when the bed-material concentration is greater than about 100 parts per million by weight. Users can either use a combination of Eqs. (3.62) and (3.64) or (3.65) and (3.64) for the computation of bed material concentration in a river, depending on sediment size in that river. If bed materials are not uniform, Eq. (3.5) is also applied in GSTAR-1D.

### 3.1.4.9 Parker's Method (1990)

Parker (1990) developed an empirical gravel transport function based on the equal mobility concept and field data. Parker's dimensionless bedload transport parameter,  $W_i^*$ , was assumed to be a single valued function of the dimensionless shear stress parameter,  $\phi_i$ , or,

$$W_i^* = f(\phi_i) \quad (3.66)$$

where the two parameters are defined as,

$$W_i^* = \frac{q_{bi}g(s-1)}{p_i(\tau_b/\rho)^{1.5}} \quad (3.67)$$

$$\phi_i = \frac{\theta_i}{\theta_c \xi_i} \quad (3.68)$$

where  $q_s$  = volumetric sediment transport rate per unit width;  $\tau_b$  = total bed shear stress,  $d_{50}$  = the median diameter;  $g$  = acceleration of gravity;  $\gamma$  = specific weight of water; and  $s$  = relative specific density of sediment ( $\rho_s/\rho$ ). Also,  $\theta_c$  = critical Shield's parameter; and  $\theta_i$  = Shield's parameter of the sediment size class  $i$  computed as:

$$\theta_i = \tau_b / (\gamma(s-1)d_i) \quad (3.69)$$

The parameter  $\xi_i$  = exposure factor, which accounts for the reduction in the critical shear stress for relatively large particles and the increase in the critical shear stress for relatively small particles:

$$\xi_i = (d_i/d_{50})^{-\alpha} \quad (3.70)$$

where  $\alpha$  = a constant usually fitted to data. The function in Eq. (3.66) was fit to field data and is:

$$f(\phi) = \begin{cases} 1 - 0.853/\phi & , \phi > 1.59 \\ 0.000183 \exp[14.2(\phi-1) - 9.28(\phi-1)^2] & , 1 < \phi \leq 1.59 \\ 0.000183\phi^{14.2} & , \phi \leq 1 \end{cases} \quad (3.71)$$

Two parameters must be defined by the user to use Parker's equation:  $\theta_c$  and  $\alpha$ . Ideally, these values should be fit to data of the stream being simulated. However, in the absence of data, several references provide guidance, such as Buffington and Montgomery (1997) and Andrews (2000).

### 3.1.4.10 Brownlie's Method

Brownlie (1981) developed a sediment transport equation based solely on dimensional analysis. The equation is best used for sand transport and yields parts per million by weight as

$$C = 7115 C_F (F_g - F_{g0})^{1.978} S_f^{0.6601} \left( \frac{R}{d_i} \right)^{-0.3301} \quad (3.72)$$

where  $C_F$  = Brownlie's coefficient for field application (=1.268);  $F_g$ ,  $F_{go}$  = the grain Froude number and critical grain Froude number, respectively, calculated as:

$$F_g = \frac{V}{\sqrt{\left(\frac{\rho_s - \rho}{\rho}\right) g d_{50}}} \quad (3.73)$$

$$F_{go} = \frac{4.596 \tau_{*c}^{0.5293}}{S_f^{0.1405} \sigma_g^{0.1606}} \quad (3.74)$$

where  $\sigma_g$  = the geometric standard deviation of bed-particle sizes ( $= \left(\frac{d_{84}}{d_{16}}\right)^{1/2}$ );

and  $\tau_{*c}$  = the critical shear stress calculated as:

$$\tau_{*c} = 0.22 Y + \frac{0.06}{(10)^{7.7Y}} \quad (3.75)$$

$$Y = \left( \sqrt{\frac{\rho_s - \rho}{\rho}} R_g \right)^{-0.6} \quad (3.76)$$

$$R_g = \frac{\sqrt{g d_{50}^3}}{v} \quad (3.77)$$

where  $R_g$  = the grain Reynolds number, and  $Y$  = temporary variable.

### **3.1.4.11 Yang et al. 's Modified Formula for Sand Transport with High Concentration of Wash Load (1996)**

Up to this point, all transport functions were developed for equilibrium sediment transport where the effects of wash load can be neglected. The existence of high concentration of wash load can significantly affect the flow viscosity, sediment fall velocity, and the relative density or relative specific weight of sediment. For a given set of hydraulic conditions, non-equilibrium sediment transport of varying rates may occur because of a varying rate of high concentration of wash load. Yang et al. (1996) rewrote Yang's 1979 formula in the following form for sediment-laden flow with high concentration of wash load:

$$\begin{aligned} \log C_{ts} &= 5.165 - 0.153 \log \frac{\omega_m d}{v_m} - 0.297 \log \frac{U^*}{\omega_m} \\ &+ \left( 1.78 - 0.36 \log \frac{\omega_m d}{v_m} - 0.48 \log \frac{U^*}{\omega_m} \right) \log \left( \frac{\gamma_m}{\gamma_s - \gamma_m} \frac{VS}{\omega_m} \right) \end{aligned} \quad (3.78)$$

where  $\omega_m$  = particle fall velocity in a sediment-laden flow;  $v_m$  = kinematic viscosity of sediment laden flow; and  $\gamma_s$ ,  $\gamma_m$  = specific weights of sediment and sediment-laden flow, respectively.

It should be noted that the coefficients in Eq. (3.78) are identical to those in Eq. (3.65). However, the values of fall velocity, kinematic viscosity, and relative

specific weight are modified for sediment transport in sediment-laden flows with high concentrations of fine suspended materials. The modifications made by Yang et al. (1996) were based on sediments from the Yellow River in China, which is noted for its high concentration of wash load and bed-material load. Similar to the applications of Eqs. (3.62), (3.64), and (3.65), Eq. (3.78) is used in conjunction with Eq. (3.5) for non-uniform bed materials.

### 3.1.5 Cohesive Sediment Aggregation

Cohesive sediments tend to aggregate to form large, low-density units. This process is strongly dependent on the type of sediment, the type and concentration of ions in the water, and the flow condition (Mehta et al. 1989). Cohesive sediments are primarily composed of clay-sized material, which have strong interparticle forces because of their surface ionic charges. As particle size decreases, the interparticle forces dominate gravitational force, and the settling velocity is no longer a function of only particle size. McAnally and Mehta (2001) provided a new formulation of the collision efficiency and collision diameter function through a non-dimensional analysis of the significant parameters in collision, aggregation, and disaggregation. In engineering models, aggregation is often indirectly considered by the change in settling velocity.

Several researchers investigated the effects of aggregation on the settling velocity. Krone (1962) performed flume studies and found settling velocity increases with sediment concentration. Cole and Miles (1983) used a linear relationship between fall velocity and sediment concentration. Van Leussen (1994) proposed an empirical relationship between settling velocity, concentration and shear stress. Nicholson and O'Connor (1986) developed a relationship for settling velocity that incorporates high concentrations of cohesive particles. Burban et al. (1990) linked the settling velocity with the median floc diameter from laboratory experiment data.

Thorn (1981) showed settling velocity increases with concentration at low concentrations, attains a maximum value, and then decreases due to hindered settling at intermediate concentrations and structural flocculation at high concentrations. Van Rijn (1993) summarized the influence of sediment concentration on the settling velocity for several types of sediments (Figure 3.6).

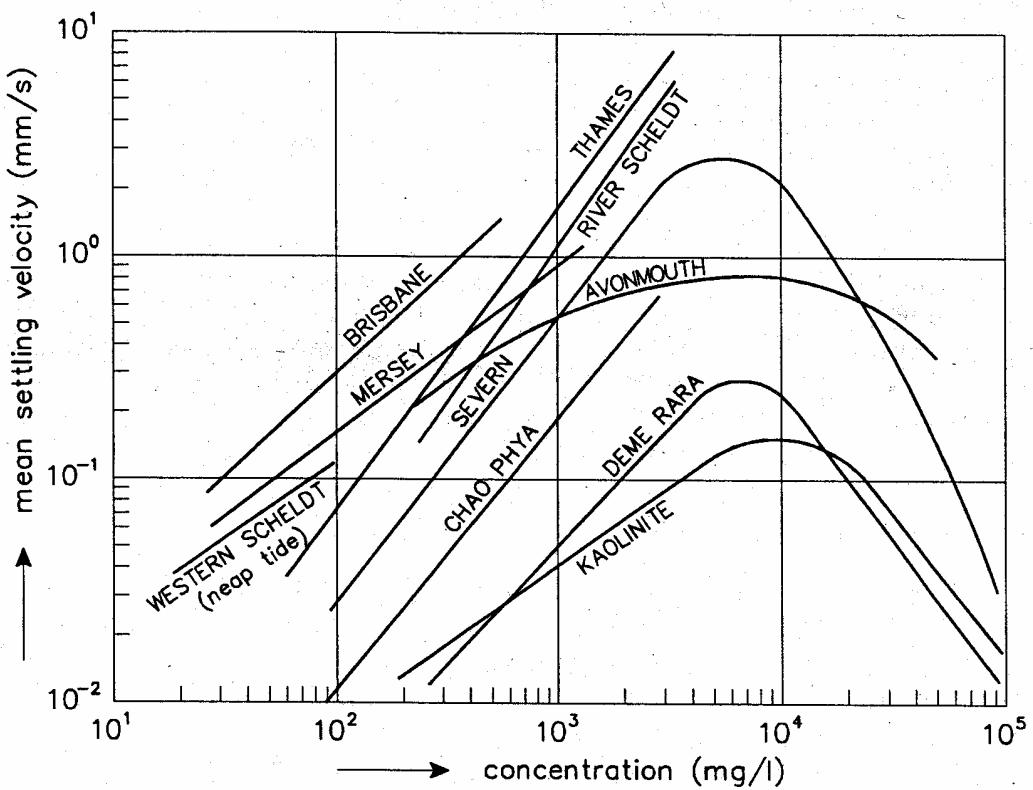


Figure 3.6 The influence of sediment concentration on the settling velocity (source: Van Rijn, 1993, figure 11.4.2)

Settling velocities due to sediment flocculating are usually site-specific and determined by experiment. GSTAR-1D allows the user to enter a set of data ( $C_1$ ,  $V_1$ ,  $C_2$ ,  $V_2$ ,  $C_3$ ,  $V_3$ ,  $C_4$ , and  $V_4$ ) as shown in Figure 3.7.

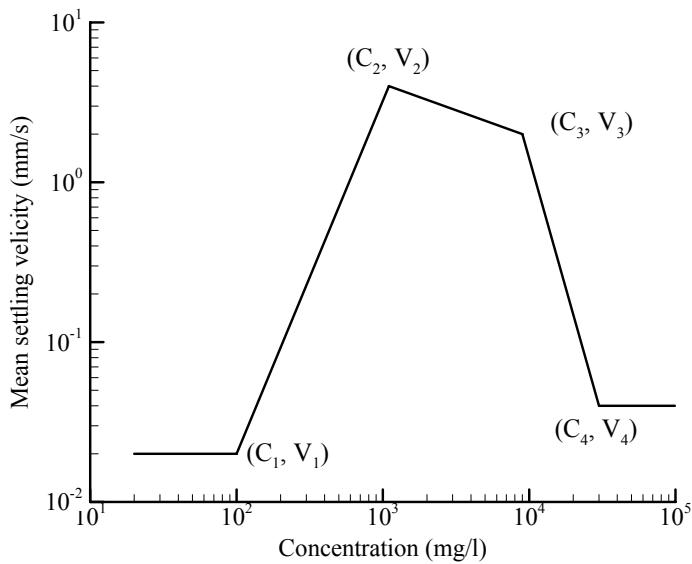


Figure 3.7 Input data illustration for settling velocity

### 3.1.6 Cohesive Sediment Deposition

Deposition occurs when the bottom shear stress is less than a critical shear stress. Only aggregates with sufficient shear strengths to withstand highly disruptive shear stresses in the near bed region will deposit and adhere to the bed. Mehta and Partheniades (1973) performed laboratory studies on the depositional behavior of cohesive sediment and found that deposition is controlled by the bed shear stress, turbulence processes in the zone near the bed, settling velocity, type of sediment, depth of flow, suspension concentration, and ionic constitution of the suspending fluid (also summarized in Hayter et al., 1999).

Two kinds of sediment deposition are included in GSTAR-1D, full and partial depositions. Van Rijn (1993) provides more information about the equations used below.

Krone's (1962) deposition formulation governs when the bed shear stress ( $\tau$ ) is smaller than the critical shear stress for full deposition ( $\tau_{d,full}$ ) and all sediment particles and flocs can deposit.

$$V_d = P_d \omega c \quad \text{for } \tau \leq \tau_{d,full} \quad (3.79a)$$

where  $V_d$  = deposition velocity, and  $P_d$  = the deposition probability. The variable  $P_d$  is also the probability of particles sticking to the bed and not being re-entrained by the flow. A fraction of sediments settling to the near bed region cannot withstand the high shear stresses at the sediment-water interface and are broken up and resuspended. The probability of deposition is given by,

$$P_d = 1 - \tau / \tau_{d,full} \quad \text{for } \tau \leq \tau_{d,full} \quad (3.79b)$$

where  $\tau$  = bottom shear stress; and  $\tau_{d,full}$  = critical shear stress for full deposition. Many experiments were performed to determine the values of critical shear stress for full deposition of cohesive sediments. They range between 0.06 and 1.1 N/m<sup>2</sup> depending upon the sediment type and concentration. Krone (1962) conducted a series of flume experiments to determine the critical shear stress for full deposition. For San Francisco Bay sediment, he found that  $\tau_{d,full} = 0.06$  N/m<sup>2</sup> when  $c < 0.3$  g/l;  $\tau_{d,full} = 0.078$  N/m<sup>2</sup> when  $0.3 < c < 10$  g/l. Mehta and Partheniades (1975) found that  $\tau_{d,full} = 0.15$  N/m<sup>2</sup> for kaolinite in distilled water.

Partial deposition exists when the bed shear stress is greater than the critical shear stress for full deposition but smaller than the critical shear stress for partial deposition (Van Rijn, 1993). At this range of bed shear stress, relatively strong flocs are deposited and relatively weak flocs remain in suspension. The partial deposition formulation is written as,

$$V_d = P_d \omega(c - c_{eq}) \quad \text{for } \tau_{d,full} < \tau < \tau_{d,part} \quad (3.79c)$$

where  $c_{eq}$  is the equilibrium cohesive sediment concentration, which is the concentration of relatively weak flocs that are broken apart before reaching the bed or eroded immediately after deposition. The probability of deposition is given by,

$$P_d = 1 - \tau / \tau_{d,part} \quad \text{for } \tau_{d,full} < \tau < \tau_{d,part} \quad (3.79d)$$

The deposition rate is zero when the bed shear stress is larger than the critical shear stress for partial deposition,

$$P_d = 0 \quad \text{for } \tau \geq \tau_{d,part} \quad (3.79e)$$

At present, the behavior of critical shear stresses for full and partial depositions are not well understood, but the accuracy of the deposition model depends on the use of correct values. When the actual value of  $\tau_{d,full}$  and  $\tau_{d,part}$  are uncertain, they become primary calibration parameters for determining the deposition rate.

### 3.1.7 Cohesive Sediment Erosion

Two kinds of erosion modes are simulated: surface and mass erosion. Surface erosion occurs when the bed shear stress is just above a critical value. At higher levels of stress, the bed shear stress exceeds the bulk shear strength of a layer of material and that layer of bed material is susceptible to mass erosion.

The excess bed shear stress, defined as  $\tau - \tau_e$ , is a measure of erosion force. The critical erosion shear stress depends on a number of factors including sediment composition, bed structure, chemical compositions of the pore and eroding fluids, deposition history, and organic matter and its state of oxidation (Ariathurai and Krone, 1976; Mehta et al., 1989). Usually, both erosion rate constant  $M$  and critical erosion shear stress  $\tau_e$  change with the bed properties in depth and time. Field studies or laboratory measurements should be made to obtain the critical shear stress and erosion rate.

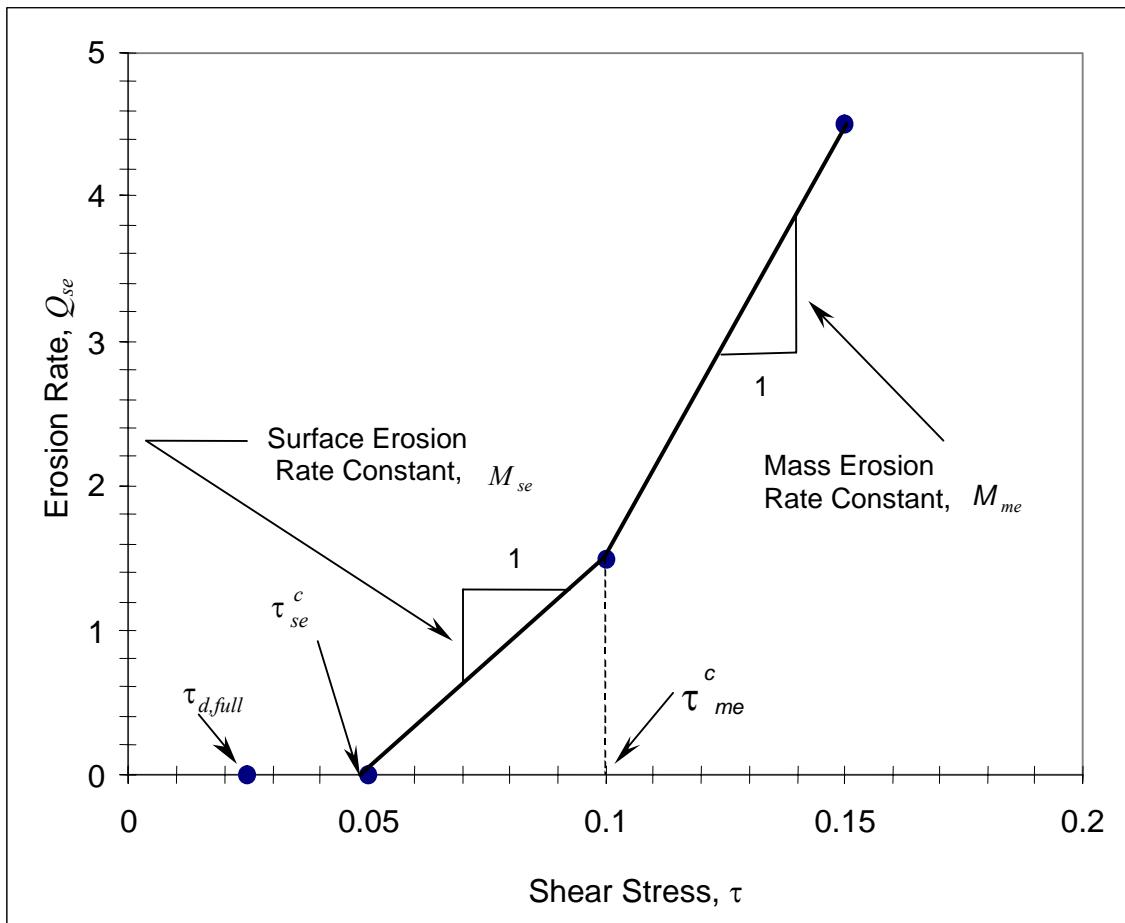


Figure 3.8 The schematic illustrates the erosional characteristics that need to be determined from erosion tests (after: Vermeyen, 1995)

Field studies and laboratory flume studies are the most reliable physical methods to determine empirical model parameters. Figure 3.8 illustrates the ideal erosional and depositional characteristics that can be determined from physical tests. In general, a physical test should provide the following information: critical shear stresses for deposition, surface erosion, mass erosion, and the erosion rates for surface and mass erosion. Measured erosion rates often exhibit large amounts of scatter or are not linearly dependent upon shear stress. However, a simple linear model is often the most reasonable approach.

A formula for surface erosion rate was described by Partheniades (1965):

$$Q_{se} = \begin{cases} M_{se} \frac{\tau - \tau_{se}^c}{\tau_{se}^c} & \tau \geq \tau_{se}^c \\ 0 & \tau < \tau_{se}^c \end{cases} \quad (3.80)$$

where  $Q_{se}$  (lb/ft<sup>2</sup>/hr or kg/m<sup>2</sup>/hr) = surface erosion rate;  $\tau$  and  $\tau_{se}^c$  (lb/ft<sup>2</sup> or kg/m<sup>2</sup>) = bed shear stress and critical surface erosion shear stress, respectively;  $M_{se}$  = surface erosion constant (lb/ft<sup>2</sup>/hr or kg/m<sup>2</sup>/hr). The GSTAR-1D model uses a modified version of Eq. (3.80):

$$Q_{se} = \begin{cases} P_{se} \left( \frac{\tau - \tau_{se}^c}{\tau_{me}^c - \tau_{se}^c} \right) & \tau \geq \tau_{se}^c \\ 0 & \tau < \tau_{se}^c \end{cases} \quad (3.81)$$

where  $\tau_{me}^c$  = critical mass erosion shear stress and  $P_{se}$  is the surface erosion constant replacing  $M_{se}$ . The modified relationship is more consistent with the mass erosion rate discussed below. The parameters  $\tau_{se}^c$  and  $P_{se}$  are site-specific and have to be determined experimentally.

Mass erosion is usually arbitrarily dependent on the model setup and its time scale. Hwang and Mehta (1989) found a maximum rate of mass erosion is on the order of 0.6 g/s/m<sup>2</sup>. The presented model uses a mass erosion equation similar to surface erosion:

$$Q_{me} = M_{me} \left( \frac{\tau - \tau_{me}^c}{\tau_{me}^c} \right) + P_{se} \quad \tau \geq \tau_{me}^c \quad (3.82)$$

where  $Q_{me}$  = mass erosion rate;  $\tau$  and  $\tau_{me}^c$  = bed shear stress and critical mass erosion shear stress, respectively;  $M_{me}$  = mass erosion constant. The erosion rates in lb/ft<sup>2</sup>/hr or kg/m<sup>2</sup>/hr are converted to the erosion velocity,  $V_e$ , through appropriate unit conversion before calculations proceed in GSTAR-1D.

### 3.2 Bed Material Mixing

This section describes the simulation of the bed material mixing processes that occur in natural river systems. Figure 3.9 provides a schematic of the conceptual model, in which the bed is composed of one active layer and  $N-1$  inactive layers. In this figure,  $h_n$  = bed thickness of layer  $n$ ,  $P_{n,k}$  = volume fraction of  $k$ -th size class in layer  $n$ . A user-defined number of size fractions will be used to represent the sediment size distributions. The bed profile is composed of a number of layers of various thicknesses and bulk densities. Each individual layer is assumed to have the same size distribution and bulk density throughout its depth. In each layer, bulk density of the cohesive sediment increases with time due to consolidation. The bulk density of the non-cohesive sediment remains constant. During consolidation, the bed thickness decreases but no mixing occurs between layers.

The active layer is defined as a thin upper zone of constant thickness that is proportional to the geometric mean of the largest size class. The constant of proportionality is user defined. The thickness of the active layer can control the rate at which the bed armors. The active layer methodology assumes that all sediment particles of a given size class inside the active layer are equally exposed to the flow.

Another phenomena simulated in GSTAR-1D is the reduction in erosion rate of non-cohesive sediment by cohesive sediment. Experimental results demonstrate that the presence of fine cohesive sediment in the bed can increase the bed's resistance to erosion. The model used by GSTAR-1D assumes that the erosion

rates of sand and gravel are limited by the entrainment rate of the silt and clay if the fraction of the silt and clay is above a user specified value.

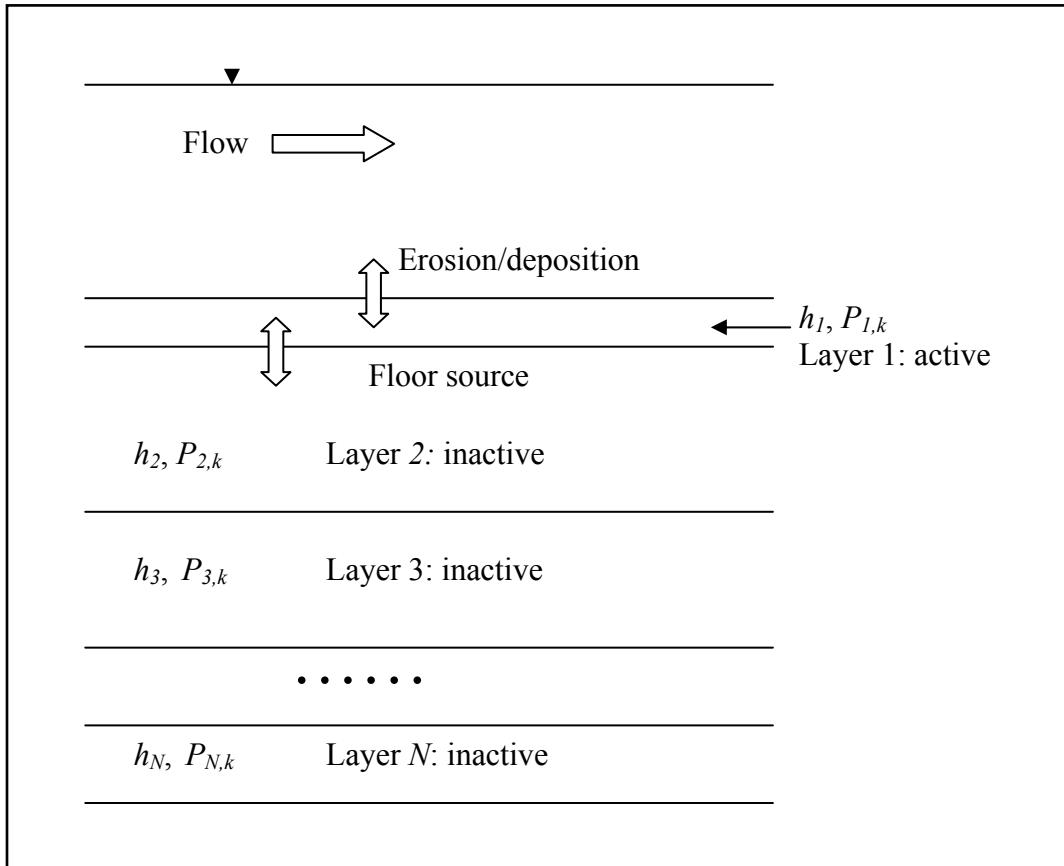


Figure 3.9 Conceptual model of bed mixing.

Armoring effects can be simulated using the active layer concept. If the bed shear stress is larger than the critical shear stress for the finer size classes, but smaller than that for coarser size classes, only the finer size classes are eroded from the active layer. This process of selective erosion will eventually armor the bed surface and prevent further erosion.

The active layer contains the bed material available for transport. During net erosion, the first inactive layer supplies material to the active layer. During net deposition, the additional material is moved to the first inactive layer. A minimum and a maximum thickness are specified for the first inactive layer. If the thickness of the first inactive layer is smaller than the minimum thickness, the first inactive layer merges with the next layer. On the other hand, if the layer thickness is larger than the maximum, it is separated into two layers. All other layers are shifted accordingly.

The notation of the active layer provides a means to model winnowing and armoring. Sediment can only be eroded from or deposited onto the active layer. The active layer thickness is defined by an auxiliary relation proportional to the geometric mean of the largest size class of the bed material at that location.

As the bed elevation descends or ascends during erosion and deposition, the active-layer floor changes its elevation to keep the active-layer thickness constant, as shown in Figure 3.9. The movement of the active-layer floor generates the active-layer floor source  $\Omega_{f,k}$  for the size class  $k$ . The kinematic condition of the  $k$ -th size fraction in the active layer can be written as:

$$h_a \frac{dP_{a,k}}{dt} = -\frac{\Omega_k}{\bar{\varepsilon}_k} + \frac{\Omega_{f,k}}{\tilde{\varepsilon}_k} \quad (3.83)$$

where subscripts  $a, k$  = active layer and size class, respectively;  $\varepsilon$  is equal to one minus porosity;  $\Omega_k$  and  $\Omega_{f,k}$  = the active layer source and floor source, respectively. During net erosion, the volume of sediment in a unit bed layer volume,  $\bar{\varepsilon}_k$ , of the active layer source term takes the value of the active layer ( $\varepsilon_{a,k}$ ) and  $\tilde{\varepsilon}_k$  of the floor source takes the value of the first non-active layer ( $\varepsilon_{2,k}$ ). On the other hand, during net deposition,  $\bar{\varepsilon}_k$  of the active layer source takes the value of the fresh deposited sediment ( $\varepsilon_{i,k}$ ) and  $\tilde{\varepsilon}_k$  of the floor source takes the value of the active layer ( $\varepsilon_{a,k}$ ). Thus  $\bar{\varepsilon}_k$  and  $\tilde{\varepsilon}_k$  can be expressed as:

$$\bar{\varepsilon}_k = \begin{cases} \varepsilon_{a,k} & \text{net erosion} \\ \varepsilon_{i,k} & \text{net deposition} \end{cases} \quad (3.84)$$

$$\tilde{\varepsilon}_k = \begin{cases} \varepsilon_{2,k} & \text{net erosion} \\ \varepsilon_{a,k} & \text{net deposition} \end{cases} \quad (3.85)$$

where subscript  $i$  = fresh deposited sediment.

Summation of Eq. (3.83) gives the global mass-conservation equation for the active layer:

$$\sum_k \frac{\Omega_k}{\bar{\varepsilon}_k} = \sum_k \frac{\Omega_{f,k}}{\tilde{\varepsilon}_k} \quad (3.86)$$

which shows that the change of the bed elevation due to erosion (or deposition) is the same as the change of the active-layer floor elevation, and the active-layer thickness remains constant.

According to the definition of the volume fraction of a size class, Eq.(3.83) can be written as:

$$\begin{aligned} h_a \frac{dP_{a,k}}{dt} &= -\frac{\Omega_k}{\bar{\varepsilon}_k} + \tilde{P}_k \sum_k \frac{\Omega_{f,k}}{\tilde{\varepsilon}_k} \\ &= -\frac{\Omega_k}{\bar{\varepsilon}_k} + \tilde{P}_k \sum_k \frac{\Omega_k}{\bar{\varepsilon}_k} \end{aligned} \quad (3.87)$$

where  $\tilde{P}_k$  can be expressed as (Hoy and Ferguson, 1994):

$$\tilde{P}_k = \begin{cases} P_{2,k} & \text{net erosion} \\ \chi p_k + (1-\chi)P_{a,k} & \text{net deposition} \end{cases} \quad (3.88)$$

where  $p_k$  is the bed load fraction, and  $\chi$  is the weight given to the bed load during the transfer of material to the sublayer and must be between 0 and 1. Toro-Escobar et al. (1996) use data collected from depositional experiments to calculate a best fit value of 0.7 for  $\chi$ . Hoy and Ferguson tested various value of  $\chi$  in numerical simulations of downstream fining. They found little affect on results for values of  $\chi$  between 0 and 0.5. The downstream fining, however, did increase significantly when the value of  $\chi$  was increased beyond 0.5. The value of  $\chi$  is specified by the user in GSTAR-1D. It should be considered a secondary calibration parameter.

The active layer source term, is calcualted using the expressions from the previous section Eqs. (3.2) and (3.39). The result is an average thickness of deposition or erosion ( $\Delta Z$ ) for each size fraction.

$$P_{a,k}^{n+1} = P_{a,k}^n - (\Delta Z_{k,i} + \Delta Z_T \tilde{P}_k) / h_a \quad (3.89)$$

The mass-conservation equation for  $k$ -th size class in active layer reads:

$$\frac{d}{dt}(\varepsilon_{a,k} P_{a,k} h_a) = -\Omega_k + \Omega_{f,k} \quad (3.90)$$

By substituting into Eq. (3.87) into Eq.(3.90), one can express the change of  $\varepsilon_{a,k}$  as:

$$\frac{d}{dt} \varepsilon_{a,k} = -(1 - \frac{\varepsilon_{a,k}}{\bar{\varepsilon}_k}) \frac{\Omega_k}{P_{a,k} h_a} + (1 - \frac{\varepsilon_{a,k}}{\bar{\varepsilon}_k}) \frac{\tilde{\varepsilon}_k \tilde{P}_k}{P_{a,k} h_a} \sum_k \frac{\Omega_{e,k}}{\bar{\varepsilon}_k} \quad (3.91)$$

Because the bed fraction appears in the sediment capacity calculation, the bed material mixing and the steady routing processes are tightly coupled. An iteration scheme is employed where the sediment routing and bed mixing calculations are repeated using updated bed fractions until the change to the bed fraction and sediment concentration between iterations is less than a specified tolerance.

Once the thickness of the first inactive layer decreases below a minimum value, the content of the layer merges with the underlying layer. The minimum thickness for the first inactive layer is the thickness of the active layer. Though merging of bed layers is not a physical process, it is a requirement of the discrete representation of the sediment bed.

During the merging of two layers, a new layer thickness is calculated as the sum of the two layers:

$$h = h_n + h_{n+1} \quad (3.92)$$

and the volume size fraction is

$$P_k = \frac{P_{n,k} h_n + P_{n+1,k} h_{n+1}}{h_n + h_{n+1}} \quad (3.93)$$

The mass conservation equation used to obtain  $\varepsilon_k$  is:

$$\varepsilon_k = \frac{\varepsilon_{n,k} P_{n,k} h_n + \varepsilon_{n+1,k} P_{n+1,k} h_{n+1}}{P_k h} \quad (3.94)$$

### 3.3 Consolidation

Consolidation changes the thickness and density of the bed through decreases in porosity. Consolidation processes also affect the tracking of size-fraction distributions within the bed because the size fraction distribution in GSTAR-1D depends on volume. Due to the slow rate of consolidation, GSTAR1-D uncouples the simulation of erosion and deposition from the bed consolidation process. Simulation of bed consolidation applies to both the active and inactive layers.

During consolidation, the mass of each size fraction remains constant. The mass-conservation equation for the sediment in each layer is:

$$\varepsilon_{n,k} P_{n,k} h_n = \text{Const} \quad (3.95)$$

where the subscripts  $n, k$  = the layer and size class indexes, respectively;  $P_{n,k}$  = volume fraction of sediment size class  $k$  in layer  $n$ ;  $\varepsilon_{n,k}$  = volume concentration of sediment size class  $k$  in layer  $n$  ( $\varepsilon = 1 - \eta$ ); and  $h_n$  = thickness of layer  $n$ ;

Eq. (3.95) can also be written as:

$$P_{n,k}^{t+\Delta t} h_n^{t+\Delta t} = \varepsilon_{n,k}^t P_{n,k}^t h_n^t / \varepsilon_{n,k}^{t+\Delta t} \quad (3.96)$$

where  $t$  = time before consolidation, and  $t+\Delta t$  = time after consolidation.

Summation of Eq. (3.96) with the constraint of size fractions  $\sum_k P_{n,k} = 1$  gives the global mass conservation equation for sediment in layer  $n$ , i.e.,

$$h_n^{t+\Delta t} = \sum_k (\varepsilon_{n,k}^t P_{n,k}^t h_n^t / \varepsilon_{n,k}^{t+\Delta t}) \quad (3.97)$$

Eqs (3.96) and (3.97) yield the expression for the size fraction change as:

$$P_{n,k}^{t+\Delta t} = \frac{\varepsilon_{n,k}^t P_{n,k}^t h_n^t / \varepsilon_{n,k}^{t+\Delta t}}{\sum_k (\varepsilon_{n,k}^t P_{n,k}^t h_n^t / \varepsilon_{n,k}^{t+\Delta t})} \quad (3.98)$$

Eqs (3.97) and (3.98) are the governing equations for bed consolidation.

The relationship in Eq. 3.50 is used to calculate the change of volume concentration of sediment at bed  $\varepsilon_{n,k}$ .

$$\varepsilon = \varepsilon_f - (\varepsilon_f - \varepsilon_i) e^{-\beta t} \quad (3.99)$$

where  $\beta$  = the consolidation coefficient, computed from user input for initial density  $\rho_i$ , fully consolidated density  $\rho_f$ , and density  $\rho_e$  at the reference time  $t_e$  by ,

$$\beta = \log \left( \frac{\rho_f - \rho_i}{\rho_f - \rho_e} \right) \quad (3.100)$$

The change of  $\varepsilon$  can be written as:

$$\frac{d\varepsilon}{dt} = \beta(\varepsilon_f - \varepsilon) \quad (3.101)$$

An explicit Euler method is used to calculate the sediment concentration after consolidation:

$$\varepsilon_{n,k}^{t+\Delta t} = \varepsilon_{n,k}^t + d\varepsilon = \varepsilon_{n,k}^t + \beta(\varepsilon_f - \varepsilon)\Delta t \quad (3.102)$$

The bed thickness and sediment size fraction are calculated from Eqs. (3.97) and (3.98).

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# 4 Bed Geometry Solution

## 4.1 Channel Geometry Adjustment

The volume of erosion or deposition is computed using the mass conservation equations described in Chapter 3. This chapter describes the methods used to apply the computed volume of erosion or deposition to the cross sections. Figure 4.1 shows the two methods GSTAR-1D uses to adjust channel geometry: vertical adjustment and width adjustment. A vertical adjustment will move all the cross section points below the water surface the same vertical distance as shown in Figure 4.1(a). A width adjustment will move the cross section points below the water surface according to the local water depth as shown in Figure 4.1(b), e.g.,  $\Delta z_i = ch_i$ , where  $\Delta z_i$  is the depth change at point  $i$ ,  $h_i$  is the water depth at point  $i$ , and  $c$  is a constant. For width adjustments, the maximum bed geometry change occurs near the bank and the thalweg elevation remains unchanged. The user can choose to allow only vertical changes or the user can select one of several methods for the automatic selection of vertical or width changes by GSTAR-1D. If floodplains are being simulated, channel adjustment in the floodplains is always assumed to occur in the vertical direction. The selection methods are only applied to the main channel.

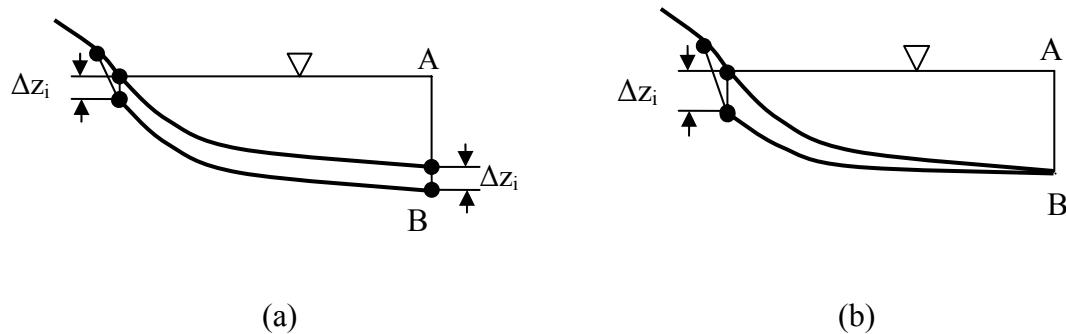


Figure 4.1 Schematic representation of channel changes: (a) vertical adjustment due to scour or deposition; (b) width adjustment due to scour or deposition. Line AB denotes the sub-channel boundary.

Limits on the erosion or deposition can be input as a function of stream distance. The vertical erosion limits are commonly encountered when bedrock or grade control structures are present. Deposition limits can be imposed when the user knows that deposition cannot occur above a certain elevation.

In some cases, erosion does not occur across the entire channel. For example, the sediment delta in a reservoir is much wider than the upstream or downstream river and as the reservoir is drawdown, or the dam is removed, the width of the incising channel is usually similar to the width of the upstream and downstream river. In GSTAR-1D, the user can specify the erosion width as a function of stream flow. The following equation is used in GSTAR-1D to determine the erosion width:

$$W_e = aQ^b \quad (4.1)$$

where  $W_e$  is the erosion width,  $Q$  is the stream flow, and  $a$  and  $b$  are user defined constants. The boundaries of the erosion width are determined by first finding the centroid, then assuming that  $W_e$  is apportioned equally on either side.

## 4.2 Theory for Channel Narrowing and Widening

The user can select one of the several methods below to allow GSTAR-1D to choose the direction of channel change. Of the following theories, only the No Minimization option or Minimization of Energy Slope have been tested and proven to provide reliable results based upon the developer's experience. It is usually recommended that the No Minimization option be initially chosen when first debugging your model runs.

### 4.2.1 No Minimization

The No Minimization option is provided so that all changes occur in the vertical direction, as shown in Figure 4.1a.

### 4.2.2 Maximization of Conveyance

This method maximizes total conveyance of the river. From Eq. (2.5), one can see that the conveyance maximization is equivalent to energy slope minimization for a single cross section.

### 4.2.3 Minimization of Total Stream Power

This procedure minimizes the total stream power along the channel, defined as

$$\Phi_T = \int \gamma Q S_f dx \quad (4.2)$$

where  $Q$  = discharge and  $S_f$  = energy slope. For one sub-channel, the same channel adjustment is performed in one direction for all cross sections. Currently, this method does account for the fact that the energy slope depends upon changes to water surface elevation.

### 4.2.4 Minimization of Energy Slope

This minimization procedure adjusts energy slope toward uniformity (Chang, 1988). A channel width reduction is usually associated with a decrease in energy gradient at a section, whereas a channel width increase is associated with an increase in energy gradient at a section. To determine the direction of channel geometry change, the energy slope at a section ( $S_{f,i}$ ) is compared with the weighted average of its adjacent sections ( $\bar{S}_{f,i}$ ), which is determined as

$$\bar{S}_{f,i} = \frac{S_{f,i+1}ds_i + S_{f,i-1}ds_{i+1}}{ds_i + ds_{i+1}} \quad (4.3)$$

where  $ds_{i-1}$ ,  $ds_i$  and  $ds_{i+1}$  = distances between sections  $i-1$ ,  $i$ , and  $i+1$ , respectively. If the energy slope  $S_{f,i}$  is greater than  $\bar{S}_{f,i}$ , the channel width at this section is reduced during deposition or the depth is increased during erosion. If the energy slope  $S_{f,i}$  is smaller than  $\bar{S}_{f,i}$ , the channel depth at this section is decreased during deposition or the width is increased during erosion.

#### 4.2.5 Minimization of Bed Slope

This minimization procedure adjusts the slope toward uniformity. To determine the direction of channel geometry change, the slope at a section ( $S_{0,i}$ ) is compared with the weighted average of its adjacent sections ( $\bar{S}_{0,i}$ ), which is determined as

$$\bar{S}_{0,i} = \frac{S_{0,i+1}ds_i + S_{0,i-1}ds_{i+1}}{ds_i + ds_{i+1}} \quad (4.4)$$

If the energy slope  $S_{0,i}$  is greater than  $\bar{S}_{0,i}$ , the channel width at this section is reduced during deposition or the depth is increased during erosion. If the slope  $S_{0,i}$  is smaller than  $\bar{S}_{0,i}$ , the channel depth at this section is decreased during deposition or the width is increased during erosion.

### 4.3 Angle of Repose Adjustments

As erosion progresses, the steepness of the bank slope will increase. The maximum allowable bank slope depends on the stability of bank materials. When erosion undermines the lower portion of the bank and the slope increases past a critical value, the bank may collapse to a stable slope. The bank slope should not be allowed to increase beyond a certain critical value. The critical angle may vary from case to case, depending on the type of soil and the existence of natural or artificial protection.

GSTAR-1D checks the angle of repose for violation of a known critical slope. The user must specify one critical angle above the water surface, and another critical angle for submerged points. GSTAR-1D scans each cross section at the end of each time step to determine if vertical or horizontal adjustments have caused the banks to become too steep. If violations occur, the two points adjacent to the segment are adjusted vertically until the slope equals the user-provided critical slope. The material taken from the bank is added as a lateral sediment input at that cross section.

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# 5 Input Data Requirements

The input data necessary to run the GSTAR-1D model may be separated into 14 data groups as listed below:

1. Model Parameters
2. Upstream Boundary Conditions
3. Downstream Boundary Conditions
4. Internal Boundary Conditions
5. Lateral Inflows
6. Channel Geometry and Flow Characteristics
7. Sediment Model Parameters
8. Upstream Sediment Boundary Conditions
9. Lateral Sediment Discharge
10. Sediment Bed Material
11. Water Temperature
12. Erosion and Deposition Limits
13. Sediment Transport Parameters
14. Cohesive Sediment Transport Parameters

The following sections describe each data group.

## 5.1 Model Parameters

The Model Parameters data group contains the input parameters that control the overall simulation. The Model Parameters contain the title of the simulation and the number of simulated rivers. The number of sediment size fractions is also set here and if no sediment transport is simulated the number of size fractions is set to zero. The number of dissolved substances can be set to one or greater if substances dissolved in the flow are being simulated. The number of bed layers is input here and must be 2 or more. A list of the records is given in Table 5.1.

Multiple floodplain options are available under record YFP, however, at this stage of model development only KFLP = 0 can be recommended. The other options are sometimes numerically unstable.

The time step is an important parameter that influences the stability and accuracy of the simulation. In general, smaller time steps will produce more stable and more accurate results. However, the computer time required for simulation is directly proportional to the number of time steps calculated. It is recommended that the time step be decreased until further decreases no longer significant affect the final answer.

Table 5.1 Input records in Model Parameter data group.

Record	Description
YTT	Title of study
YNR	Dimension of problem (i.e. number of rivers, size fractions, dissolved substances, and bed layers)
YSL	Solution parameters
YFP	Floodplain option and minimum flow
YTM	Time of simulation
YDT	Simulation time step and output time step

## 5.2 Upstream Flow Boundary Conditions

The upstream flow boundary condition can be specified as a junction to another river, a stage time series or a water discharge time series. When a time series is specified and the simulated time falls between the given values, interpolation is required. The interpolation is linear in time when unsteady flow is specified. If steady flow is specified, no interpolation is performed and the water discharge or stage does not change until the time of the next input water discharge is reached. An example of the steady flow approximation of a water discharge hydrograph is shown in Figure 5.1.

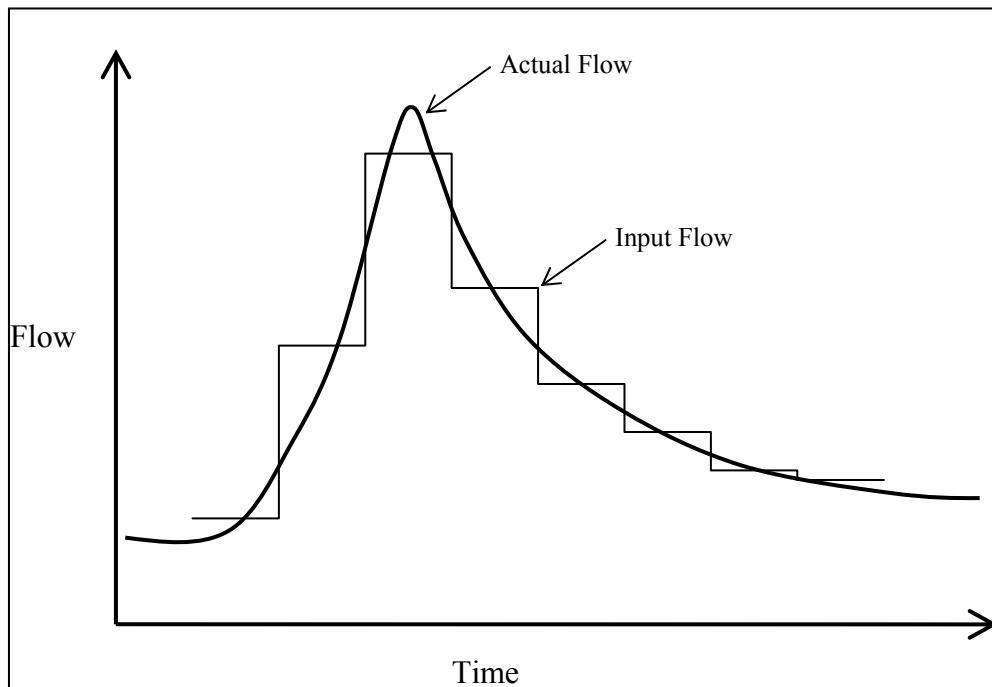


Figure 5.1 Steady Flow Representation of a Water Discharge Hydrograph.

## 5.3 Downstream Flow Boundary Conditions

Several different types of downstream boundary conditions are possible. A water discharge rating curve specifies the relationship between water discharge and elevation. The downstream boundary condition can also be a times series of water surface elevations or, for unsteady flow, water discharge. For time series data, the interpolation between given values is performed the same as for the upstream

flow boundary condition. A weir boundary condition can also be specified where the weir elevation, width, and discharge coefficient are given. The rating curve option is similar to the water discharge versus water surface elevation table, but the user just enters the coefficients in a power relationship between water discharge and water surface elevation.

Table 5.2 Possible downstream boundary conditions.

<b>Record</b>	<b>Description</b>
D00	Junction – this river is linked to another river
D01	Time versus water surface elevation table
D02	Time versus water discharge table (only available for unsteady flow)
D03	Water discharge versus water surface elevation table
D04	Weir
D09	Rating Curve relationship between water discharge and water surface elevation

## 5.4 Internal Boundary Conditions

Many of the same boundary conditions that can be applied at the downstream end of the modeled reach can also be used at internal cross sections. In addition, bridges and radial gates can be modeled. The types of permissible internal boundary conditions, along with their record identification are given in Table 5.3.

Table 5.3 Possible internal boundary conditions.

<b>Record</b>	<b>Description</b>
I 01	Time versus water surface elevation table
I 02	Time versus water discharge table (only available for unsteady flow)
I 03	Water discharge versus water surface elevation table
I 04	Weir
I 05	Normal Depth – a bed slope is given
I 06	Bridge
I 08	Radial Gate – inline or side discharge
I 09	Rating Curve relationship between water discharge and water surface elevation

## 5.5 Lateral Inflows

Lateral inflows can be specified anywhere along a river reach according to the stream distance where the lateral inflow enters. Each lateral inflow requires a time series table of water discharge.

## 5.6 Channel Geometry and Flow Characteristics

GSTAR-1D represents the river in a manner similar to other 1D models. The river is described by discrete cross sections located at specified intervals (Figure 5.2). The cross sections are chosen by the user to represent important hydraulic

behaviors of the river and all the controls that may exist on that river. The distance between the cross sections is termed the reach length. The reach length should be appropriate to the problem being solved. Many factors control the choice of cross section location and reach lengths, but some guidelines are given below (modified from Samuels, 1990):

1. Select all sites of key interest.
2. Select cross sections adjacent to major structures and control points.
3. Select cross sections representative of the river geometry.
4. As a first estimate, select cross sections 20 times the channel width apart.
5. Select sections a maximum of  $0.2Y/S_0$  apart, where  $Y$  is the depth and  $S_0$  is the bed slope.
6. For unsteady flow modeling, select sections a maximum of  $L/30$  apart, where  $L$  is the length of the physically important flood wave.
7. Cross sections spacing must be greater than the survey horizontal error and greater than the computer's precision for representing distance.
8. The ratio of the area between two adjacent cross sections should be between  $2/3$  and  $3/2$ .
9. Cross-sectional spacing may have to be reduced for shallow flows where the average of the friction slope between cross sections has a large error.

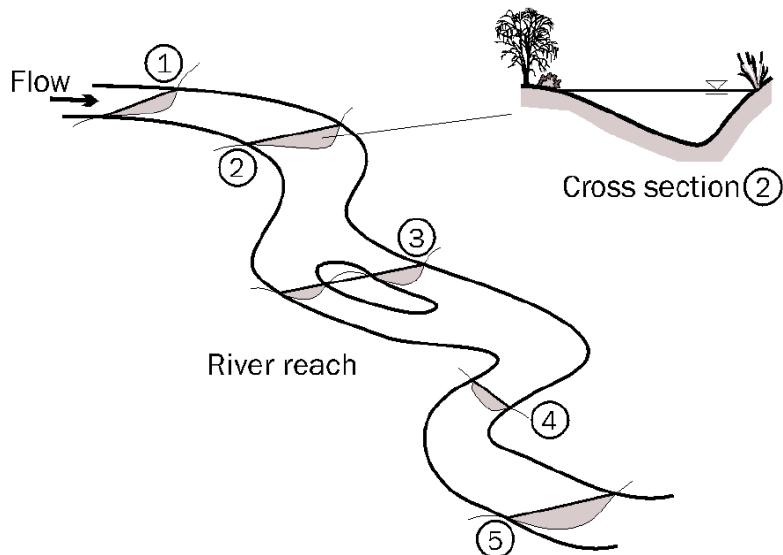


Figure 5.2 Representation of River by Discrete Cross sections

The GSTAR-1D cross section geometry representation was developed similar to the HEC-RAS representation. The cross section representation used in HEC-RAS can be found in the Hydraulic Reference Manual of HEC-RAS 3.1 (Brunner, 2002). An example of a cross section is shown in Figure 5.3. Three components

are required for every cross section. The cross section points describe the geometry. The over bank points distinguish the main channel from the floodplain. For braided streams, these points should be located on the left most and right most points of the active channels. Roughness coefficients are defined for segments of the cross section. The user may define one to 10 different roughness segments for each cross section. The Manning's equation is used to calculate friction loss. Many references describe the selection of the Manning's roughness coefficients. A pictorial guide of roughness characteristics of streams is found in Barnes (1987). Extensive tables of Manning's roughness coefficient values are found in Chow (1959). Cowan (1956) and Arcement and Schneider (1987) use various factors, such as bed material type, vegetation, channel meandering, etc. and develop a method for computing Manning's roughness coefficients based on individual modifications. There have also been several attempts to develop equations to predict Manning's  $n$  value based upon water discharge and bed material characteristics. For example, see Einstein and Barbarossa (1952), Engelund and Hansen (1966), Richardson and Simon (1967), Limerinos (1970), White et al. (1979), Griffiths (1981), van Rijn (1982), Brownlie (1983), Jarrett (1984), Karim and Kennedy (1990), and Yang (1996).

Optional flow areas are available to restrict conveyance in a cross section. The options are designed similar to those of HEC-RAS. These options include temporary ineffective flow areas, permanent ineffective flow areas, dry areas, and blocked areas. Ineffective flow is used to define a portion of a cross section where water is not actively conveyed. In an ineffective flow area, water ponds and the velocity of the water is close to zero. Temporary ineffective flow areas become effective once the water surface rises above the defined elevations. Permanent ineffective flow areas are used to define a portion of a cross section where the water is always ineffective below the established elevation, and effective above the elevation. Dry areas are used to define an area protected by levees. No water is allowed in the area until the levee elevation is exceeded. Blocked areas are used to define a portion of a cross section permanently blocked by a hydraulic structure or other feature.

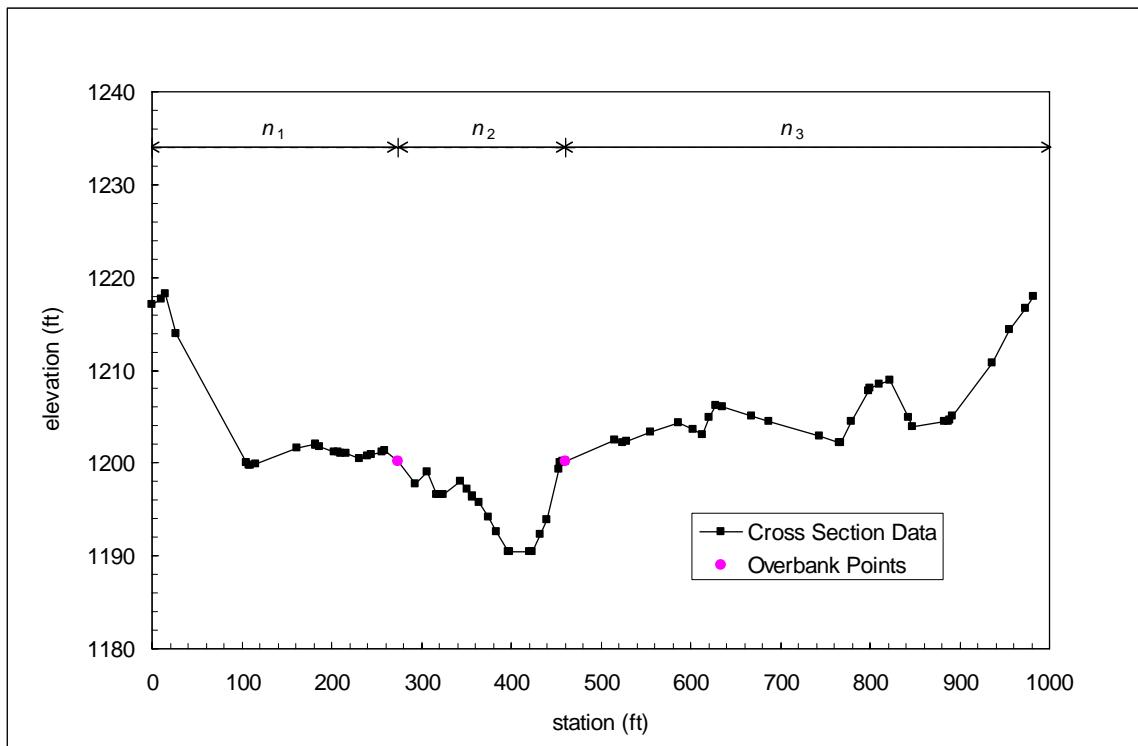


Figure 5.3 Representation of Cross Section by Discrete Points.

## 5.7 Sediment Model Parameters

Sediment model parameters control the implicit factor for sediment transport computations and number of sediment time steps performed for each hydraulic time step. The implicit factor should be set to 1. The number of sediment time steps may be set to greater than 1 if model results are unstable. Stability could also be increased by shortening the overall time step (in Data Group 1). The sediment size groups are also given in this data group.

## 5.8 Sediment Boundary Conditions

Sediment entering a reach at an upstream boundary must be specified for each size fraction. There are several ways to specify incoming sediment loads:

1. An equilibrium sediment load can be assumed. If this option is chosen, then the sediment load coming into the reach is calculated based on the bed material and the sediment transport equation specified in Data Group 13. The hydraulics of the most upstream section are used in the transport equation.
2. A sediment rating curve is used. The sediment rating curve is a power relationship between flow and total sediment discharge. The total sediment discharge is divided into fractional sediment discharge using a table of water discharge and fraction of total sediment load for each size fraction.

3. A total sediment load versus discharge table is specified. This option is similar to the previous option except that a table is used to specify the sediment discharge instead of a power function.
4. The total sediment load is specified as a time series. The user may directly specify the amount of sediment entering the reach as a function of time. The total sediment discharge is divided into the sediment size fractions similar to the previous two options.

Ideally, to determine the amount of sediment entering a reach, there is a sediment measuring station at the most upstream cross section of the model. However, this is rarely the case. It may be necessary to calculate an approximate incoming load based upon bed material and a sediment transport function. The sediment transport function generally should be consistent with the Sediment Transport Parameters Data Group.

## 5.9 Lateral Sediment Discharge

A lateral sediment discharge can be specified for each lateral inflow specified in Data Group 5. The lateral sediment discharge is specified in the same way as the upstream sediment discharge.

## 5.10 Sediment Bed Material

The percentage of each sediment size fraction present in the initial river bed is required for each river reach. The information is given at specific locations or select cross sections and interpolated to the rest of the river. Edwards and Glysson (1999) describe bed material sampling methods and equipment appropriate for material finer than medium gravel (less than 8 mm) as well as those appropriate for larger material. Bunte and Abt (2001) provide a comprehensive detailed description of available methods.

## 5.11 Water Temperature

The water temperature is input for each river as a time series. Presently, a uniform temperature is assumed throughout the river.

## 5.12 Erosion and Deposition Limits

The erosion and deposition limits control the allowable extents of cross section change. No deposition is allowed above the maximum vertical limit and no erosion is allowed below the minimum vertical limit. The points to the left of the minimum horizontal erosion limit and to the right of the maximum horizontal erosion limit are not allowed to erode. The points to the left of the minimum horizontal deposit limit and to the right of the maximum horizontal deposit limit are not allowed to deposit.

The constants used to determine the erosion width are also set here. These are commonly required when such processes as incision through reservoir deltas are being simulated.

## 5.13 Sediment Transport Parameters

The Sediment Transport Parameters Data Group contains several parameters used in the computation of sediment transport. These are given in Table 5.4. The number of sub-channels define the number of channels within the main channel. The stream tube concept used in previous GSTARS versions is no longer used in GSTAR-1D to simulate lateral variations of flow and sediment conditions. Therefore, it is recommended that the user define only one sub-channel for sediment transport computations in the main channel.

The minimization option controls how channel geometry changes. Currently, only the no minimization option or the minimization of energy slope options are recommended.

The angle of repose defines the maximum bank angle within the cross section. This information can be taken from field data of bank angles.

The model may be sensitive to the sediment transport equation chosen. No one equation can be recommended for all rivers. Ideally, the sediment transport equation should be compared against actual sediment load measurements. Yang and Huang (2001) analyzed the performance of some commonly used formulas.

The active layer thickness is also set here. The active layer thickness is an important parameter in determining the rate at which the simulated river responds to changes in sediment load. The active layer thickness is the thickness over which mixing of sediment occurs. As the active layer thickness increases, the bed fractions of the active layer thickness will change more slowly. Therefore, armoring occurs more slowly. Conversely, as the active layer thickness decreases, armoring will occur more rapidly. Often, the coefficient that is multiplied by a representative particle diameter to obtain the active layer thickness is a calibration parameter.

Table 5.4 Records used in Sediment Transport Parameters data group.

Record	Description
STU	Number of sub-channels
SMN	Minimization option – 0 if no minimization performed
SEQ	Sediment transport equation
SA0	Location of sediment transport parameters in SAT
SAT	Sediment transport parameters – angle of repose, active layer thickness, non-equilibrium factors, diffusion coefficients

## 5.14 Cohesive Sediment Transport Parameters

Sediment particles smaller than 0.0625 mm are assumed cohesive sediment and require several parameters to define their transport characteristics (Table 5.5). The

physical significance of the parameters are given in Sections 3.1.5 to 3.1.7. Additional guidance on the parameter values can be found in Huang et al. (2004).

Table 5.5 Parameters necessary for cohesive sediment erosion and deposition.

Parameter	Description
Fall velocity, $\omega$	Controls the rate at which deposition occurs
Critical shear stress for full deposition, $\tau_{d,full}^c$	Deposition will occur at shear stresses below $\tau_{d,full}^c$ .
Critical shear stress for partial deposition, $\tau_{d,part}^c$	Partial deposition will occur at shear stresses below $\tau_{d,part}^c$ and above $\tau_{d,full}^c$ .
Equilibrium concentration for partial deposition, $c_{eq}$	Equilibrium concentration during partial deposition
Critical shear stress for surface erosion, $\tau_{se}^c$	Surface erosion occurs above $\tau_{se}^c$ and below $\tau_{me}^c$ .
Critical shear stress for mass erosion, $\tau_{me}^c$	Mass erosion occurs above $\tau_{me}^c$ .
Rate Constant for Surface Erosion, $M_{se}$	Slope of surface erosion rate versus shear stress line
Rate Constant for Mass Erosion, $M_{me}$	Slope of mass erosion rate versus shear stress line
Initial bulk density, $\rho_i$	Initial bulk density of cohesive sediment
Final bulk density, $\rho_f$	Final bulk density after full consolidation
Time to reference bulk density, $t_e$ , and reference bulk density, $\rho_e$	$t_e$ and $\rho_e$ are used to compute, $\beta$ , which is the consolidation parameter controlling the rate of consolidation

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# 6 Running GSTAR-1D

## 6.1 Input Data Format

GSTAR-1D reads a single input file that contains all the necessary information to perform a simulation. An input file is organized in sequential records. The sequence is presented in a flow chart in Appendix A. A record is a line of up to 300 characters in length. A line starting with “\*\*\*” is a comment line and will be ignored by the model. A record starts with a specific record name containing 3 characters. Each record name is unique and inputs specific data to the program. A comprehensive list of all records names used by GSTAR-1D is given in Appendix B. A detailed explanation of all the records is given in Appendix C. Not all records are used (for example, some are mutually exclusive) but they have to be in an appropriate sequence.

Data after the record name is in an unformatted form to prevent unnecessary errors. Error checking is provided to prevent some human errors, which include:

- empty lines;
- lines started with space instead of the record name;
- incorrect record names;
- incorrect number of data following the record name;
- incorrect data values.

The data are prepared in ASCII files. For easy data input, sample examples are provided in the Microsoft EXCEL format, users may save the data in type of “Text Formatted (Space delimited) \*.prn”. It is recommended that the user study the example input files included in the distribution of GSTAR-1D to become familiar with the input data format. The unused records are hidden in the EXCEL files and can be viewed by highlighting rows, right clicking the mouse, and the selecting the ‘unhide’ function from the menu. The EXCEL sample input files also contain the explanation of each variable in the comment field.

## 6.2 Executing GSTAR-1D

After preparing the input data file, GSTAR-1D can be executed within windows by double-clicking the filename in Windows Explorer. GSTAR-1D can also be used from the command line interface (DOS window – see your system’s user’s manual for more information regarding your particular computer) like any conventional DOS program. At the prompt simply type:

C:> GSTAR1D.EXE FILENAME.DAT

or

C:> GSTAR1D.EXE -e FILENAME.DAT

The argument “-e” in the command line forces the program to exit all windows when the program is terminated.

Make sure the executables exist in the system PATH variable. If GSTAR-1D is launched without an input file name, the program prompts the user to enter it. For consistency, the input data file should have an extension .DAT (or .dat), but the program will work with any other extension. The FILENAME.DAT argument can also include the drive letter and path information if the entire string is encapsulated by quotes.

GSTAR-1D displays the current bed profile and user specified cross sections during the simulation. Using this real time display, one can monitor the simulation during a run. This feature is useful in debugging the simulation.

## 6.3 Output Files

For a given input file named sample.dat, the following files may be generated.

**sample\_OUT.dat:** the \*\_OUT.dat file first summarizes the dimensions used by the model, such as the river number, the sediment size fractions, the bed layer number, the cross section number, the maximum points in a cross section, etc. Then it echoes the input data. When an error occurs on reading the input files, the users should first check this file for possible warnings.

**sample\_ERR.dat:** the \*\_ERR.dat file contains errors encountered during run time. If the program stops, please check this file for error messages.

**sample\_HEC\_RAS\_GEOMETRY.g01:** the \*\_HEC\_RAS\_GEOMETRY.g01 is a HEC-RAS geometry file. It is updated each DTPLT time step defined in record YDT. User may use HEC\_RAS model to check the initial input geometry and the final geometry.

**sample\_OUT\_Profile.dat:** the \*\_OUT\_Profile.dat file is the bed profile file, which contains the cross section number, the original cross section number, the cross section location, the discharge, the lateral water discharge, the original thalweg elevation, the current thalweg elevation, the current water surface elevation, the average bed elevation of the main channel, the friction slope, the channel top width, the hydraulic radius, the sediment sizes  $d_{16}$ ,  $d_{35}$ ,  $d_{50}$ ,  $d_{86}$ , and the bed shear stress.

**sample\_OUT\_XC.dat:** the \*\_OUT\_XC.dat file contains the cross section data. The program will not permit the cross section file to be written more than 20 times.

**sample\_OUT\_MaterialVolume.dat:** the \*\_OUT\_MaterialVolume.dat file contains the cumulative material volume of deposition in all sub-channels and in each sub-channel.

**sample\_OUT\_Volume.dat:** the \*\_OUT\_Volume.dat file contains the cumulative volume of deposition material in all size fractions and as calculated in the main channel and left and right floodplains.

**sample\_OUT\_MassBalance.dat:** the \*\_MassBalance.dat file is the mass balance file, which contains the mass balance, sediment coming in from upstream entrances, sediment flowing out from downstream exits, sediment coming in from

lateral point and not-point sources, and sediment erosion. The sediment mass balance is only valid for a steady sediment transport model.

**sample\_OUT\_Conc.dat**: the **\*\_OUT\_Conc.dat** file contains the sediment concentration data of each size fraction in each sub-channel.

**sample\_OUT\_BedLayer.dat**: the **\*\_OUT\_BedLayer.dat** file contains the bed thickness data of each bed layer in each sub-channel.

**sample\_OUT\_BedFraction.dat**: the **\*\_OUT\_BedFraction.dat** file contains the sediment size fraction data of each bed layer in each sub-channel.

**sample\_OUT\_Porosity.dat**: the **\*\_OUT\_Porosity.dat** file contains the sediment porosity data of each bed layer in each sub-channel.

**sample\_OUT\_SedimentLoad.dat**: the **\*\_OUT\_SedimentLoad.dat** file contains the sediment load passing each cross section for each size fraction in each sub-channel.

**sample\_OUT\_TimeSeries.dat**: the **\*\_OUT\_TimeSeries.dat** file contains time series information at the cross sections being viewed on screen during run time.

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# APPENDIX A - Flow Chart of Input Data Records

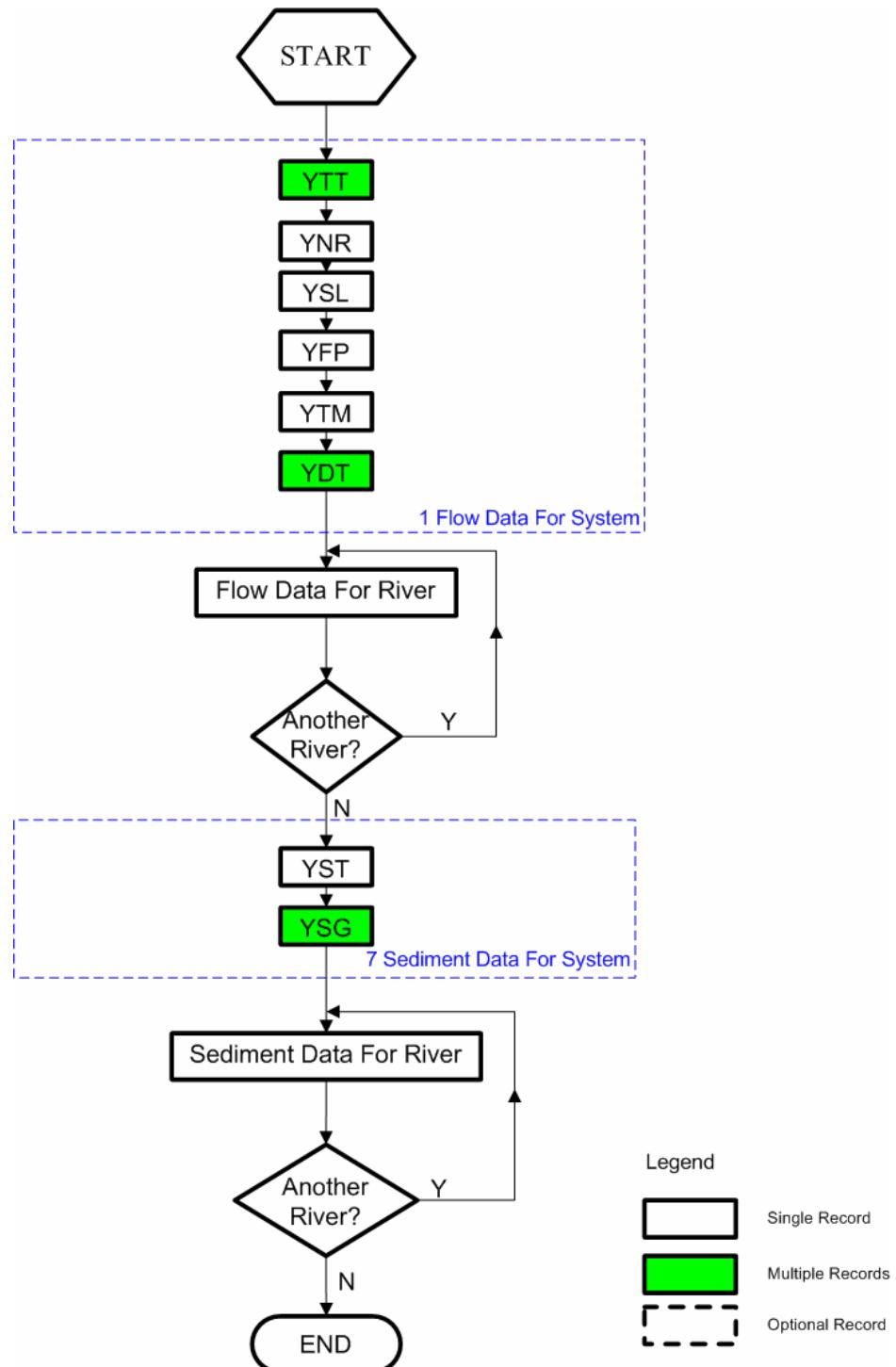


Figure A-1 Flowchart of input data records

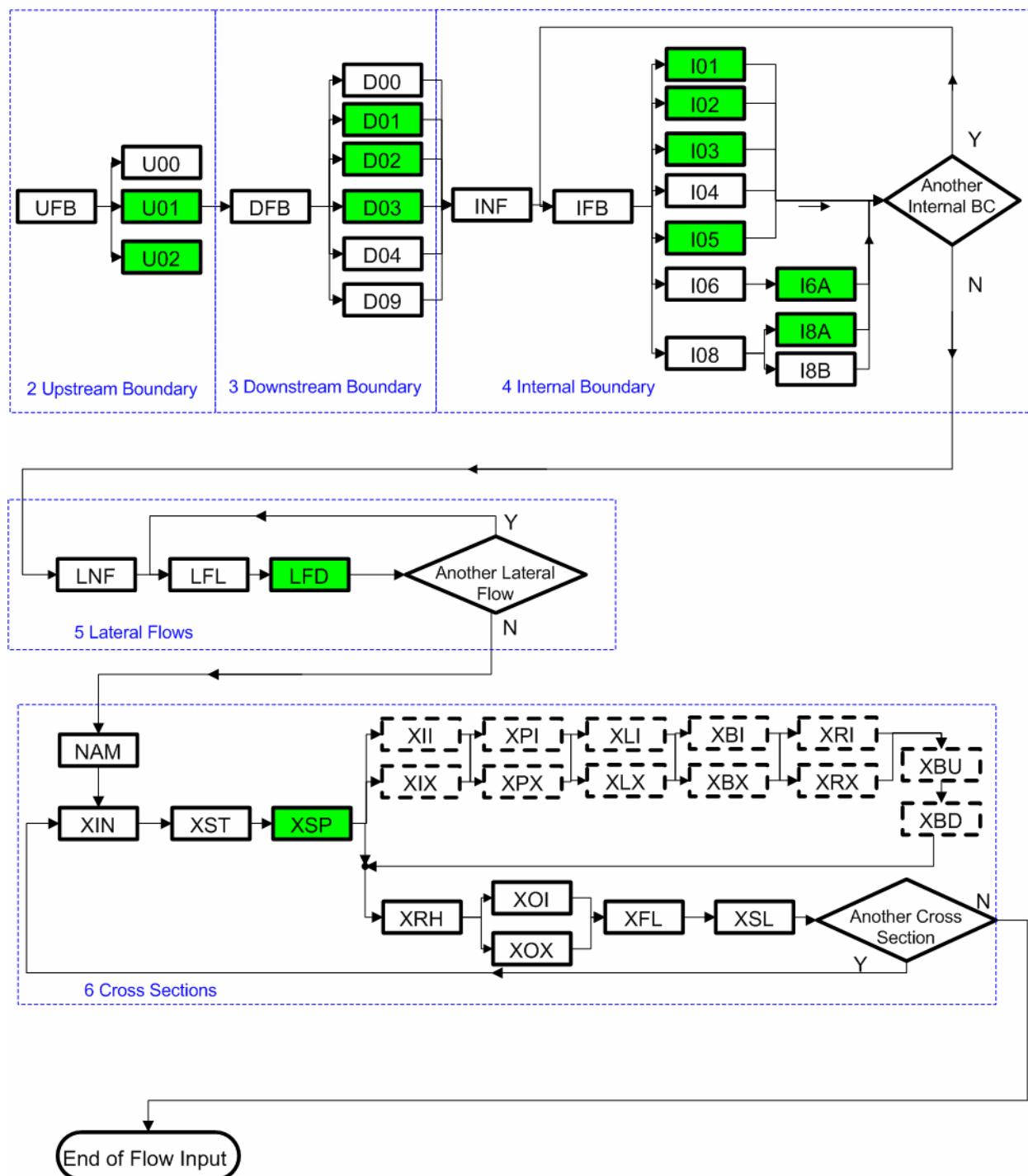


Figure A-2 Flowchart of flow data records for a river

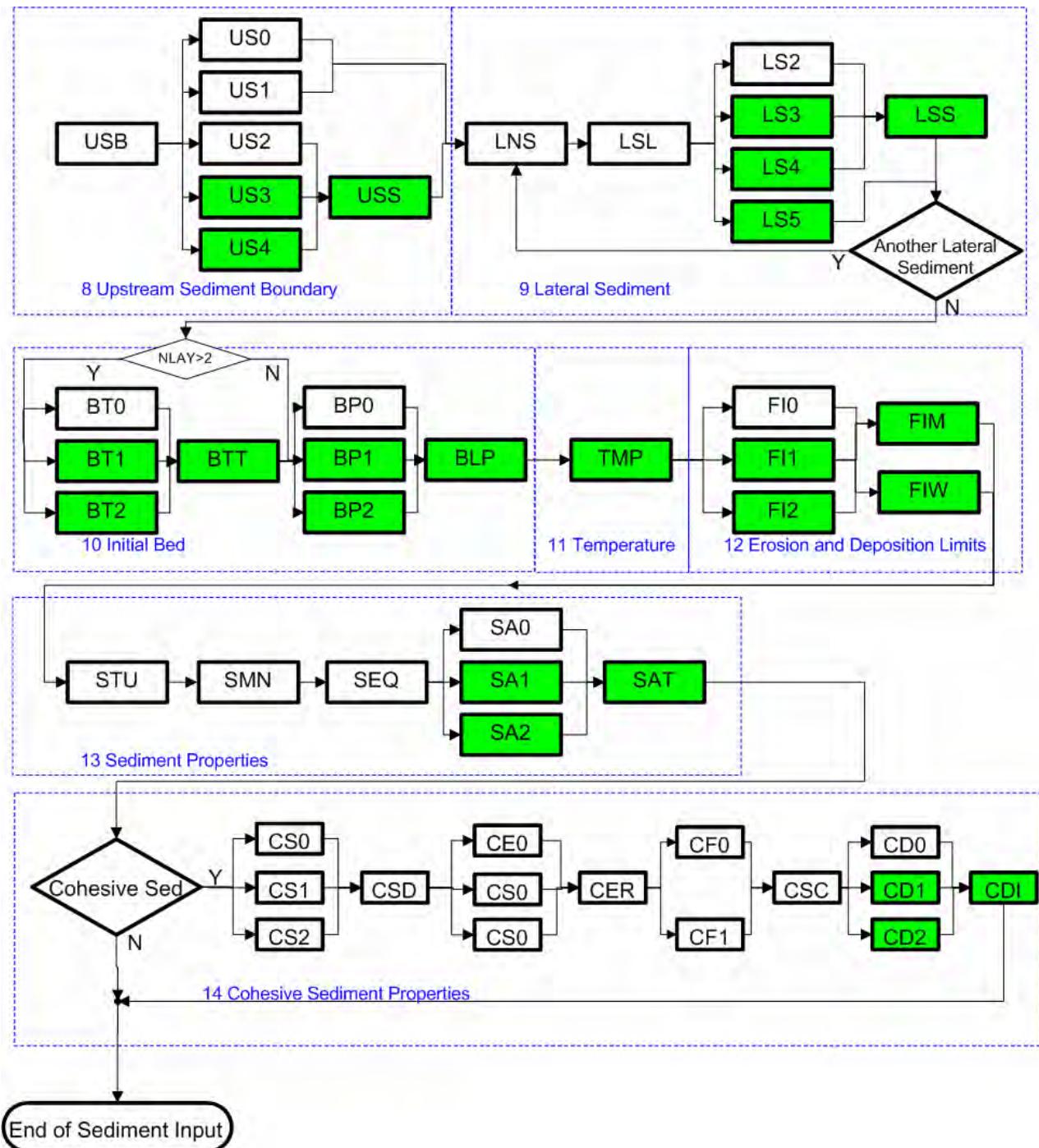


Figure A-3 Flowchart of sediment data records for a river

# APPENDIX B – List of the Input Data Records

## Alphabetical List

<u>Record: Explanation</u>	<u>Page in Appendix C</u>
YTT: TITLE OF STUDY .....	2
YNR: DIMENSIONS .....	3
YSL: SOLUTION PARAMETERS .....	4
YFP: FLOOD PLAIN OPTION AND MINIMUM DISCHARGE .....	5
YTM: TIME .....	6
YDT: TIME STEP .....	7
UFB: UPSTREAM FLOW BOUNDARY CONDITION .....	8
U00: UPSTREAM FLOW BOUNDARY CONDITION ----- JUNCTION .....	9
U01: UPSTREAM FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	10
U02: UPSTREAM FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	11
DFB: DOWNSTREAM FLOW BOUNDARY CONDITION .....	12
D00: DOWNSTREAM FLOW BOUNDARY CONDITION ----- JUNCTION .....	13
D01: DOWNSTREAM FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	14
D02: DOWNSTREAM FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	15
D03: DOWNSTREAM FLOW BOUNDARY CONDITION ----- DISCHARGE-STAGE TABLE .....	16
D04: DOWNSTREAM FLOW BOUNDARY CONDITION ----- WEIR .....	17
D09: DOWNSTREAM FLOW BOUNDARY CONDITION ----- RATING CURVE .....	18
INF: INTERNAL FLOW BOUNDARY CONDITION ----- NUMBER .....	19
IFB: INTERNAL FLOW BOUNDARY CONDITION ----- LOCATION AND TYPE .....	20
I01: INTERNAL FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	21
I02: INTERNAL FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	22
I03: INTERNAL FLOW BOUNDARY CONDITION ----- DISCHARGE-STAGE TABLE .....	23
I04: INTERNAL FLOW BOUNDARY CONDITION ----- WEIR .....	24
I05: INTERNAL FLOW BOUNDARY CONDITION ----- NORMAL DEPTH .....	25
I06, I6A: INTERNAL FLOW BOUNDARY CONDITION ----- BRIDGE .....	26
I08, I8A, I8B: INTERNAL FLOW BOUNDARY CONDITION ----- RADIAL GATE .....	29
LNF: LATERAL FLOWS ----- NUMBER .....	31
LFL: LATERAL FLOW INPUTS ----- LOCATION .....	32
LFD: LATERAL FLOW INPUTS ----- TIME-DISCHARGE TABLE .....	33
NAM: NUMBER AND NAME OF RIVER .....	34
XIN: STATION ----- INITIAL CONDITION .....	35
XST: STATION ----- LOCATION .....	36
XSP: STATION ----- CROSS SECTION GEOMETRY .....	37
XII/XIX: STATION ----- INEFFECTIVE FLOW AREA .....	38
XPI/XPX: STATION ----- PERMANENT INEFFECTIVE FLOW AREA .....	39
XLI/XLX: STATION ----- DRY AREAS .....	40
XBI/XBX: STATION ----- BLOCKED AREAS .....	41

XRI/XRX: STATION ----- RIP RAP LOCATIONS.....	42
XBU: STATION ----- UPSTREAM BREAK POINTS.....	43
XBD: STATION ----- DOWNSTREAM BREAK POINTS .....	44
XRH: STATION ----- ROUGHNESS COEFFICIENTS.....	45
XOI/XOX: STATION ----- BANK LOCATION .....	46
XFL: STATION ----- CROSS SECTION ENERGY LOSS COEFFICIENT.....	47
XSL: STATION ----- GEO-REFERENCED CROSS SECTION POSITIONS.....	48
YST: SEDIMENT SOLUTION PARAMETERS .....	49
YSG: SEDIMENT SIZE GROUP .....	50
USB: UPSTREAM SEDIMENT BOUNDARY CONDITION .....	51
US0: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- JUNCTION .....	52
US1: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- SEDIMENT TRANSPORT EQUATION.....	53
US2: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- RATING CURVE .....	54
US3: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- FLOW-SEDIMENT DISCHARGE TABLE .....	55
US4: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE.....	56
USS: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- SEDIMENT SIZE DISTRIBUTION.....	57
LNS: NUMBER OF LATERAL SEDIMENT INPUTS .....	58
LSL: LOCATION OF LATERAL SEDIMENT INPUT.....	59
LS2: LATERAL SEDIMENT DISCHARGE – RATING CURVE .....	60
LS3: LATERAL SEDIMENT DISCHARGE – FLOW-SEDIMENT DISCHARGE TABLE .....	61
LS4: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE.....	62
LS5: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE FOR EACH SIZE FRACTION .....	63
LSS: LATERAL SEDIMENT DISCHARGE SEDIMENT SIZE DISTRIBUTION .....	64
BT0/BT1/BT2: BED PROPERTIES ----- LOCATION OF THICKNESS .....	65
BTT: BED PROPERTIES ----- THICKNESS .....	66
BP0/BPI/BP2: BED PROPERTIES ----- LOCATION OF SIZE FRACTIONS.....	67
BPL: BED PROPERTIES ----- SEDIMENT SIZE FRACTIONS.....	68
TMP: WATER TEMPERATURE .....	69
FI0/FI1/FI2: BED LIMITATION LOCATIONS.....	70
FIM: BED LIMITATIONS .....	71
FIW: BED LIMITATIONS AND EROSION LIMITS DEFINED BY FLOW .....	73
STU: NUMBER OF SUB-CHANNELS AND WIDTH ADJUSTMENTS .....	75
SMN: SEDIMENT PROPERTIES ----- MINIMIZATION OPTION .....	76
SEQ: SEDIMENT TRANSPORT EQUATION .....	77
SA0/SA1/SA2: SEDIMENT TRANSPORT ----- LOCATION FOR SEDIMENT TRANSPORT PROPERTIES INPUT .....	78
SAT: SEDIMENT TRANSPORT ----- PROPERTIES .....	79
CS0/CS1/CS2: COHESIVE SEDIMENT DEPOSITION ----- LOCATIONS .....	81
CSD: COHESIVE SEDIMENT DEPOSITION ----- PARAMETERS .....	82
CE0/CE1/CE2: COHESIVE SEDIMENT EROSION ----- LOCATIONS.....	83
CER: COHESIVE SEDIMENT EROSION ----- PARAMETERS .....	84
CF0/CF1: COHESIVE SEDIMENT ----- FALL VELOCITY .....	86

CSC: COHESIVE SEDIMENT ----- CONSOLIDATION.....	87
CD0/CD1/CD2: COHESIVE SEDIMENT ----- LOCATION OF COHESIVE SEDIMENT DENSITY IN BED.....	88
CDI: COHESIVE SEDIMENT ----- COHESIVE SEDIMENT DRY BULK DENSITY IN BED.....	89
END: END OF INPUT .....	90

## Sequential List

<u>Record: Explanation</u>	<u>Page in Appendix C</u>
<b>TAPPENDIX A - FLOW CHART OF INPUT DATA RECORDS .....</b>	<b>1</b>
<b>APPENDIX B – LIST OF THE INPUT DATA RECORDS.....</b>	<b>1</b>
<b>APPENDIX C - DESCRIPTIONS OF RECORDS.....</b>	<b>1</b>
<b>DATA GROUP 1. MODEL PARAMETERS.....</b>	<b>2</b>
YTT: TITLE OF STUDY .....	2
YNR: DIMENSIONS .....	3
YSL: SOLUTION PARAMETERS .....	4
YFP: FLOOD PLAIN OPTION AND MINIMUM DISCHARGE .....	5
YTM: TIME .....	6
YDT: TIME STEP .....	7
<b>DATA GROUP 2. UPSTREAM BOUNDARY CONDITIONS .....</b>	<b>8</b>
UFB: UPSTREAM FLOW BOUNDARY CONDITION .....	8
U00: UPSTREAM FLOW BOUNDARY CONDITION ----- JUNCTION .....	9
U01: UPSTREAM FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	10
U02: UPSTREAM FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	11
<b>DATA GROUP 3. DOWNSTREAM BOUNDARY CONDITION .....</b>	<b>12</b>
DFB: DOWNSTREAM FLOW BOUNDARY CONDITION .....	12
D00: DOWNSTREAM FLOW BOUNDARY CONDITION ----- JUNCTION.....	13
D01: DOWNSTREAM FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	14
D02: DOWNSTREAM FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	15
D03: DOWNSTREAM FLOW BOUNDARY CONDITION ----- DISCHARGE-STAGE TABLE.....	16
D04: DOWNSTREAM FLOW BOUNDARY CONDITION ----- WEIR.....	17
D09: DOWNSTREAM FLOW BOUNDARY CONDITION ----- RATING CURVE.....	18
<b>DATA GROUP 4. INTERNAL BOUNDARY CONDITIONS.....</b>	<b>19</b>
INF: INTERNAL FLOW BOUNDARY CONDITION ----- NUMBER .....	19
IFB: INTERNAL FLOW BOUNDARY CONDITION ----- LOCATION AND TYPE.....	20
I01: INTERNAL FLOW BOUNDARY CONDITION ----- TIME-STAGE TABLE .....	21
I02: INTERNAL FLOW BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE .....	22
I03: INTERNAL FLOW BOUNDARY CONDITION ----- DISCHARGE-STAGE TABLE.....	23
I04: INTERNAL FLOW BOUNDARY CONDITION ----- WEIR .....	24
I05: INTERNAL FLOW BOUNDARY CONDITION ----- NORMAL DEPTH .....	25
I06, I6A: INTERNAL FLOW BOUNDARY CONDITION ----- BRIDGE .....	26
I08, I8A, I8B: INTERNAL FLOW BOUNDARY CONDITION ----- RADIAL GATE ...	29
<b>DATA GROUP 5. LATERAL FLOW INPUTS .....</b>	<b>31</b>

LNF: LATERAL FLOWS ----- NUMBER .....	31
LFL: LATERAL FLOW INPUTS ----- LOCATION .....	32
LFD: LATERAL FLOW INPUTS ----- TIME-DISCHARGE TABLE .....	33
<b>DATA GROUP 6. CHANNEL GEOMETRY AND FLOW CHARACTERISTICS.....</b>	<b>34</b>
NAM: NUMBER AND NAME OF RIVER .....	34
XIN: STATION ----- INITIAL CONDITION .....	35
XST: STATION ----- LOCATION .....	36
XSP: STATION ----- CROSS SECTION GEOMETRY .....	37
XII/XIX: STATION ----- INEFFECTIVE FLOW AREA .....	38
XPI/XPX: STATION ----- PERMANENT INEFFECTIVE FLOW AREA.....	39
XLI/XLX: STATION ----- DRY AREAS .....	40
XBI/XBX: STATION ----- BLOCKED AREAS.....	41
XRI/XRX: STATION ----- RIP RAP LOCATIONS.....	42
XBU: STATION ----- UPSTREAM BREAK POINTS.....	43
XBD: STATION ----- DOWNSTREAM BREAK POINTS .....	44
XRH: STATION ----- ROUGHNESS COEFFICIENTS.....	45
XOI/XOX: STATION ----- BANK LOCATION .....	46
XFL: STATION ----- CROSS SECTION ENERGY LOSS COEFFICIENT.....	47
XSL: STATION ----- GEO-REFERENCED CROSS SECTION POSITIONS .....	48
<b>DATA GROUP 7. SEDIMENT MODEL PARAMETERS .....</b>	<b>49</b>
YST: SEDIMENT SOLUTION PARAMETERS .....	49
YSG: SEDIMENT SIZE GROUP .....	50
<b>DATA GROUP 8. SEDIMENT BOUNDARY CONDITIONS .....</b>	<b>51</b>
USB: UPSTREAM SEDIMENT BOUNDARY CONDITION .....	51
US0: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- JUNCTION .....	52
US1: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- SEDIMENT TRANSPORT EQUATION.....	53
US2: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- RATING CURVE .....	54
US3: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- FLOW-SEDIMENT DISCHARGE TABLE .....	55
US4: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE.....	56
USS: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- SEDIMENT SIZE DISTRIBUTION .....	57
<b>DATA GROUP 9. LATERAL SEDIMENT INFLOWS .....</b>	<b>58</b>
LNS: NUMBER OF LATERAL SEDIMENT INPUTS .....	58
LSL: LOCATION OF LATERAL SEDIMENT INPUT.....	59
LS2: LATERAL SEDIMENT DISCHARGE – RATING CURVE .....	60
LS3: LATERAL SEDIMENT DISCHARGE – FLOW-SEDIMENT DISCHARGE TABLE .....	61
LS4: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE.....	62
LS5: UPSTREAM SEDIMENT BOUNDARY CONDITION ----- TIME-DISCHARGE TABLE FOR EACH SIZE FRACTION .....	63
LSS: LATERAL SEDIMENT DISCHARGE SEDIMENT SIZE DISTRIBUTION .....	64
<b>DATA GROUP 10. SEDIMENT BED MATERIAL .....</b>	<b>65</b>
BT0/BT1/BT2: BED PROPERTIES ----- LOCATION OF THICKNESS .....	65
BTT: BED PROPERTIES ----- THICKNESS .....	66

BP0/BPI/BP2: BED PROPERTIES ----- LOCATION OF SIZE FRACTIONS .....	67
BPL: BED PROPERTIES ----- SEDIMENT SIZE FRACTIONS.....	68
<b>DATA GROUP 11. WATER TEMPERATURE.....</b>	<b>69</b>
TMP: WATER TEMPERATURE .....	69
<b>DATA GROUP 12. EROSION AND DEPOSITION LIMITS .....</b>	<b>70</b>
FI0/FI1/FI2: BED LIMITATION LOCATIONS.....	70
FIM: BED LIMITATIONS .....	71
FIW: BED LIMITATIONS AND EROSION LIMITS DEFINED BY FLOW .....	73
<b>DATA GROUP 13. SEDIMENT TRANSPORT PARAMETERS.....</b>	<b>75</b>
STU: NUMBER OF SUB-CHANNELS AND WIDTH ADJUSTMENTS .....	75
SMN: SEDIMENT PROPERTIES ----- MINIMIZATION OPTION .....	76
SEQ: SEDIMENT TRANSPORT EQUATION .....	77
SA0/SA1/SA2: SEDIMENT TRANSPORT ----- LOCATION FOR SEDIMENT TRANSPORT PROPERTIES INPUT .....	78
SAT: SEDIMENT TRANSPORT ----- PROPERTIES .....	79
<b>DATA GROUP 14. COHESIVE SEDIMENT PARAMETERS .....</b>	<b>81</b>
CS0/CS1/CS2: COHESIVE SEDIMENT DEPOSITION ----- LOCATIONS .....	81
CSD: COHESIVE SEDIMENT DEPOSITION ----- PARAMETERS .....	82
CE0/CE1/CE2: COHESIVE SEDIMENT EROSION ----- LOCATIONS.....	83
CER: COHESIVE SEDIMENT EROSION ----- PARAMETERS .....	84
CF0/CF1: COHESIVE SEDIMENT ----- FALL VELOCITY .....	86
CSC: COHESIVE SEDIMENT ----- CONSOLIDATION.....	87
CD0/CD1/CD2: COHESIVE SEDIMENT ----- LOCATION OF COHESIVE SEDIMENT DENSITY IN BED.....	88
CDI: COHESIVE SEDIMENT ----- COHESIVE SEDIMENT DRY BULK DENSITY IN BED.....	89
END: END OF INPUT .....	90

# **APPENDIX C - Descriptions of Records**

The following sections detail the input data for each of the 14 data groups. Each record is defined by a three letter code followed by variables. Each variable can be one of three types: text, integer (int), or real number data. Each record may contain several variables. Each variable is described as follows:

Variable: Gives the variable name.

Type: The type can be either text, integer (int), or real (float).

Value: Give the potential ranges for this variable.

Description: Describes the significance of this variable.

# Data Group 1. Model Parameters

## YTT

YTT: Title of Study

Optional

The YTT record is used to define the title of the simulation. Any number of YTT records can be used. The text will be echoed to the output files generated by GSTAR-1D.

If a river network is simulated, records YTT to YDT are common data for the entire network. Records UFB to XSL are specified for each river.

YTT TITIL

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TITIL	text		Title of study

# YNR

## YNR: Dimensions

Required

The YNR record defines the number of rivers, the number of sediment size classes, and the number of bed layers to be used by the program. If more than one river is studied, the program should be organized with the most upstream river being river number 1 and proceeding downstream. If the number of sediment size classes is set to 0, no sediment transport process will be studied and no sediment information is required. The minimum number of bed layers is 2 (an active layer and one inactive layer).

YNR    NRIV            NF        NTOX            NLAY

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
NRIV	int	+	Number of rivers
NF	int	0/+	Number of sediment size classes
NTOX	int	0/+	Number of dissolved substances being modeled
NLAY	int	2+	Number of bed layers

# YSL

## YSL: Solution parameters

Required

The YSL record specifies the solution method used to compute the hydraulics, the solution method used to compute the sediment transport, the calculation tolerance, the implicit factor, the streamwise distance scaling factor, metric option, and the cross section coordinate order.

YSL	ISOLVE YZ	ISOLVES	EPSY	F1	XFACT	METRIC
-----	--------------	---------	------	----	-------	--------

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
ISOLVE	int		Type of flow solution
		0	Steady flow, normal depth default
		1	Steady flow, critical depth default
		2	Unsteady flow, diffusive wave
		3	Unsteady flow, dynamic wave, LPI technique
		4	Unsteady flow, dynamic wave
ISOLVES	int		Type of sediment solution
concentration		1	Ignore changes in suspended sediment
concentration		2	Calculate changes in suspended sediment
EPSY	float	+	Calculating tolerance for flow and sediment
F1	float	+	Implicit factor for unsteady flow, not used for steady flow
XFACT	float	+	Scaling factor, the cross-section streamwise distance will be multiplied by this factor
METRIC	int		Metric units option
		0	English unit
		1	Metric Unit
YZ	int		Coordinate Order
		0	ZY order, bed elevation (Z value) followed by the lateral location (Y value)
		1	YZ order, lateral location (Y value) followed by the bed elevation (Z value)

# YFP

## YFP: Flood Plain Option and Minimum Discharge

Required

GSTAR-1D has the ability to calculate the erosion/deposition in the floodplain separately from the main channel. The record YFP defines controls whether or not the program simulates the erosion/deposition in main channel differently with that in floodplains. Currently, it is recommended that KFLP = 1 or 2 be only used under very special circumstances. Often these options produce unstable results. YFP record defines a minimum flow discharge, under which no hydraulic calculations or sediment transport is simulated. It can be set to zero the user wants to include all flows in the hydrology record.

YFP            KFLP            QMIN

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KFLP	int		Floodplain Option.
		0	No Floodplain simulation
concept		1	Floodplain simulation using sub-channel
		2	Only main channel contributes to sediment transport capacity
QMIN Discharges	float	0/+	Minimum flow discharge to be calculated. smaller than this value will be ignored.

# YTM

## YTM: Time

Required

YTM record defines the total time of simulation.

YTM            THE    IHOTST

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
THE	float	+	Total time of simulation (hr)
IHOTST	int	0/1	Option to start the calculation
		0	Start the calculation from time 0
		1	Start the calculation from last saved calculation

# **YDT**

## **YDT: Time Step**

Required

This record defines the time step for flow simulation and for printing. This record also defines the cross section numbers that will be displayed on the screen during the simulation. More than one YDT record can be used. No interpolation and extrapolation is used. If the time step is smaller than the time TDT at the first record, the time step at the first record is used. If the time step is larger than the time TDT at the last record, the time step at the last record is used. Multiple XCPLT numbers can be specified, with a maximum of 10 suggested.

YDT	TDT	DT	DTPLT	XCPLT
<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>	
TDT	float	+	Time (hr) when time step is defined (increases in each record)	
DT	float	+	Time step (hr) at time TDT	
DTPLT	float	+	Time interval (hr) at time TDT to output data	
XCPLT	int	+	Cross section number for on-screen plotting at time TDT	

## Data Group 2. Upstream Boundary Conditions

### UFB

**UFB:** Upstream Flow Boundary Condition

Required

The UFB record specifies the upstream flow boundary condition type.

If a river network is simulated, records YTT to YDT are common flow data for the entire network. Records UFB to XSL are specified for each river.

UFB            KU

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KU	int	0/+	Type of upstream boundary condition
		0	Junction
		1	Table (time, stage)
		2	Table (time, flow rate).

# U00

## U00: Upstream Flow Boundary Condition ----- Junction

Optional, required only if KU = 0 in record UFB

The U00 record specifies which rivers connect to the upstream end of the river. The record ID is followed by other river indexes at the junction. A positive number is used if the connecting river is entering the junction and negative number is used if the connecting river is exiting the junction. If flow direction is not known before the simulation is run, a flow direction can be assumed and a negative discharge for that river at the junction indicates that flow is in the other direction. The program organizes the rivers in ascending order with river 1 being the most upstream.

U00            URIV(1:nu)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
URIV	int	-/+	River indexes at the junction
		+	Flow enters junction
		-	Flow exits junction
nu	int	+	Number of rivers connected with the river at upstream

# U01

## U01: Upstream Flow Boundary Condition ----- Time-Stage Table

Optional, required only if KU = 1 in record UFB

The U01 record defines the upstream flow boundary condition as a time-stage table. The U01 record is repeated until the entire table is input. This record can only be used for unsteady flow simulations.

U01            T1            ST1

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T1	float	+	time (hr)
ST1	float	+	river stage (cfs or cms) at upstream at time T1

# U02

## U02: Upstream Flow Boundary Condition ----- Time-Discharge Table

Optional, required only if KU = 2 in record UFB

The U02 record defines the upstream flow boundary condition as a time-discharge table. The U02 record is repeated until the entire table is input. One record is used for each time-discharge pair. The U02 record is repeated until the entire table is input. For steady flow, no interpolation of discharge is performed and the discharge becomes a step function in time. Changes to the discharge occur at the times input in the time-discharge table. For unsteady flow, the discharges are interpolated in time between the specified  $T_1$  values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < T_{1_1}$  the discharge for  $T_{1_1}$  is used; if  $T > T_{1_n}$  the discharge for  $T_{1_n}$  is used, where  $n$  is the total last row of the table. If there is no discharge before the first value or after the last value, a zero discharge should be added at the beginning or end of the table, respectively.

U02            T1            ST1

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T1	float	+	time (hr)
ST1	float	+	river discharge (cfs or cms) at upstream at time T1

## Data Group 3. Downstream Boundary Condition

### DFB

DFB: Downstream Flow Boundary Condition

Required

The DFB record specifies the downstream flow boundary condition type.

DFB            KD

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KD	int	0/+	Type of upstream boundary condition
		0	Junction
		1	Table (time, stage)
		2	Table (time, discharge)
		3	Table (discharge, stage)
		4	Weir flow
		5	Normal depth
		9	Rating curve with coefficients

# D00

## D00: Downstream Flow Boundary Condition ----- Junction

Optional, required only if KD = 0 in record DFB

The D00 record specifies which rivers connect to the downstream end of the river. The record ID is followed by other river indexes at the junction. A positive number is used if the connecting river is entering the junction and negative number is used if the connecting river is exiting the junction. If flow direction is not known before the simulation is run, a flow direction can be assumed and a negative discharge for that river at the junction indicates that flow is in the other direction. The program organizes the rivers in ascending order with river 1 upstream.

D00            DРИV(1:nd)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
DРИV	int	-/+	River index at the junction
		+	Flow enters junction
		-	Flow exits junction
nd	int	+	Number of rivers connected with the river at downstream

# D01

## D01: Downstream Flow Boundary Condition ----- Time-Stage Table

Optional, required only if KD = 1 in record DFB

The D01 record defines the downstream flow boundary condition as a time-stage table. The record ID is followed by one pair of time and stage data. The D01 record is repeated until the entire table is input.

D01            TN        STN

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TN	float	+	Time (hr)
STN	float	+	River stage (ft or m) at downstream at time
TN			

# D02

## D02: Downstream Flow Boundary Condition ----- Time-Discharge Table

Optional, required only if KD = 2 in record DFB

The D02 record defines the downstream flow boundary condition as a time-discharge table. The record ID is followed by one pair of time and discharge data. The D02 record is repeated until the entire table is input. For unsteady flow, the discharges are interpolated in time between the specified T1 values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < TN_1$  the discharge for  $TN_1$  is used; if  $T > TN_n$  the discharge for  $TN_n$  is used, where  $n$  is the total last row of the table. For steady flow, this record should not be used.

D02            TN            STN

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TN	float	+	Time (hr)
STN	float	+	Discharge (cfs or cms) at downstream boundary at time TN

# D03

## D03: Downstream Flow Boundary Condition ----- Discharge-Stage Table

Optional, required only if KD = 3 in record DFB

The D03 record defines the downstream flow boundary condition as a discharge-stage table. The record ID is followed by one pair of discharge and stage data. The D03 record is repeated until the entire table is input.

D03            TN        STN

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TN	float	+	Discharge (cfs or cms)
STN	float	+	Stage (ft or m) at downstream at time TN

# D04

## D04: Downstream Flow Boundary Condition ----- Weir

Optional, required only if KD = 4 in record DFB

The D04 record defines the weir downstream flow boundary condition. The record ID is followed by three weir parameters: weir height  $H_0$ , weir width  $B$ , and weir constant  $C$ . For free flowing weirs, the discharge is calculated as  $Q = CB(H - H_0)^{3/2}$ , where  $H$  is the elevation of the total energy head upstream of the weir.

D04            WEIR\_HEIGHT        WEIR\_WIDTH        WEIR\_CONST

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
WEIR_HEIGHT	float	+	Weir elevation, $H_0$ (ft or m)
WEIR_WIDTH	float	+	Weir width, $B$ (ft or m)
WEIR_CONST	float	+	Weir constant, $C$ ( $\text{ft}^{1/2}/\text{s}$ or $\text{m}^{1/2}/\text{s}$ )

# D09

## D09: Downstream Flow Boundary Condition ----- Rating Curve

Optional, required only if KD = 9 in record DFB

The D09 record defines the rating curve downstream flow boundary condition. The record ID is followed by three rating curve parameters:  $a$ ,  $b$ , and  $c$ . The river stage is calculated as,  $H = aQ^b + c$ , where  $Q$  is the flow discharge and  $H$  is the river stage.

D09            RC\_A            RC\_B            RC\_C

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
RC_A	float	0/+	Parameter a
RC_B	float	0/+	Parameter b
RC_C	float	-/0/+	Parameter c

## Data Group 4. Internal Boundary Conditions

### INF

INF: Internal Flow Boundary Condition ----- Number

Required

The INF record specifies the number of internal flow boundary conditions.

INF            NKI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KKI	int	0/+	Number of internal flow boundary conditions
		0	No internal flow boundary conditions. Skip records IFB to I8B
		n	n internal flow boundary conditions, repeat records IFB to I8B for n times

# IFB

## IFB: Internal Flow Boundary Condition ----- Location and Type

Required

The IFB record specifies the location and type of internal flow boundary condition. Records IFB to I8B should be skipped if NKI = 0 in record INF or should be repeated if NKI>1 for each internal boundary.

IFB            NXI            KI            XTI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
NXI	int	+	Station number immediately upstream of internal bc
KI	int	+	Type of internal boundary condition
		1	Time-stage table
		2	Time-discharge table
		3	Discharge-stage table
		4	Weir
		5	Normal depth
		6	Bridge
		7	Dam (not currently available)
		8	Radial gate
XTI		+	Distance from the boundary to the station NXI

# I01

## I01: Internal Flow Boundary Condition ----- Time-Stage Table

Optional, required only if KI = 1 in record IFB

The I01 record defines the internal flow boundary condition as a time-stage table. The record ID is followed by one pair of time and stage data. The I01 record is repeated until the entire table is input.

I01            T2            ST2

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T2	float	+	time (hr)
ST2	float	+	river stage (ft or m) at upstream at time T2

# I02

## I02: Internal Flow Boundary Condition ----- Time-Discharge Table

Optional, required only if KI = 2 in record IFB

The I02 record defines the internal flow boundary condition as a time-discharge table. The record ID is followed by one pair of time and discharge data. The I02 record is repeated until the entire table is input. For steady flow simulations, this record should not be used.

I02            T2            ST2

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T2	float	+	Time (hr)
ST2	float	+	Discharge (cfs or cms) at internal boundary at time T2

# I03

## I03: Internal Flow Boundary Condition ----- Discharge-Stage Table

Optional, required only if KI = 3 in record IFB

The I03 record defines the internal flow boundary condition as a discharge-stage table. The record ID is followed by one pair of discharge and stage data. The I03 record is repeated until the entire table is input.

I03            T2            ST2

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T2	float	+	Discharge (cfs or cms)
ST2	float	+	Stage (ft or m) at internal boundary condition at time T2

# I04

## I04: Internal Flow Boundary Condition ----- Weir

Optional, required only if KI = 4 in record IFB

The I04 record defines the weir internal flow boundary condition. The record ID is followed by three weir parameters: weir height  $H_0$ , weir width B, and weir constant C. For free flowing weirs, the discharge is calculated as  $Q = CB(H - H_0)^{3/2}$ , where H is the elevation of the total energy head.

I04	WEIR_HEIGHT	WEIR_WIDTH	WEIR_CONST
	WEIR_DIR		

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
WEIR_HEIGHT	float	+	Weir elevation, $H_0$ (ft or m)
WEIR_WIDTH	float	+	Weir width, B (ft or m)
WEIR_CONST	float	+	Constant, C ( $\text{ft}^{1/2}/\text{s}$ or $\text{m}^{1/2}/\text{s}$ )
WEIR_DIR	int	0/1	Weir direction
		0	Inline weir
		1	Lateral weir

# I05

## I05: Internal Flow Boundary Condition ----- Normal Depth

Optional, required only if KI = 5 in record IFB

The I05 record defines the normal depth internal flow boundary condition.

I05            T2            ST2

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T2	float	+	Time (hr)
ST2	float	+	Slope at internal boundary at time T2

# I06, I6A

## I06, I6A: Internal Flow Boundary Condition ----- Bridge

Optional, required only if KI = 6 in record IFB

The I06 record defines the bridge internal flow boundary condition. One I06 is used for one bridge, and records I6A are used to input elevation-opening table of the bridge. The record ID I6A is followed by one pair of elevation and opening data. The I6A record is repeated until the entire table is input. The present model uses the equations in FLDWAV (Fread and Lewis, 1998) for highway/railway bridges and their associated earthen embankments. The discharge can be expressed as,

$$Q = \sqrt{2g} CA_{br} (h_i - h_{i+1} + V_i^2 / 2g - \Delta h_f)^{1/2} + cc_u L_u k_u (h_i - h_{cu})^{3/2} + cc_l L_l k_l (h_i - h_{cl})^{3/2} \quad (C1)$$

$$\text{where } k_u = 1.0 \quad \text{if } h_{ru} \leq 0.76 \quad (C2)$$

$$k_u = 1.0 - c_u (h_{ru} - 0.76)^3 \quad \text{if } h_{ru} > 0.76 \quad (C3)$$

$$c_u = 133(h_{ru} - 0.78) + 10 \quad \text{if } 0.76 < h_{ru} \leq 0.96 \quad (C4)$$

$$c_u = 400(h_{ru} - 0.96) + 34 \quad \text{if } h_{ru} > 0.96 \quad (C5)$$

$$h_{ru} = (h_{i+1} - h_{cu}) / (h_i - h_{cu}) \quad (C6)$$

$$cc_u = 3.02(h_i - h_{cu})^{0.015} \quad \text{if } 0 < h_u \leq 0.15 \quad (C7)$$

$$cc_u = 3.06 + 0.27(h_u - 0.15) \quad \text{if } h_u > 0.15 \quad (C8)$$

$$h_u = (h_i - h_{cu}) / w_u \quad (C9)$$

$$\Delta h_f = \Delta x_i (Q_{br} / K_i)^2 \quad (C10)$$

$$Q_{br} = \sqrt{2g} CA_{br} (h_i - h_{i+1} + V_i^2 / 2g)^{1/2} \quad (C11)$$

$$V = Q_i / A_i \quad (C12)$$

where  $C$  = bridge coefficient;  $A_{br}$  = cross-section flow area of the downstream end of bridge opening which is user-specified via a tabular relation of wetted top width versus elevation;  $h_{cu}$  = elevation of the upper embankment crest;  $h_i$  = water surface elevation at section  $i$  (slightly upstream of bridge);  $h_{i+1}$  = water surface elevation at section  $i+1$  (slightly downstream of bridge);  $V$  = velocity of flow within the bridge opening;  $L_u$  = length of the upper embankment crest perpendicular to the flow direction including the length of bridge at elevation  $h_{cu}$ ;  $L_l$  = length of the lower embankment crest perpendicular to the flow direction including the length of bridge at elevation  $h_{cl}$ ;  $k_u$ ,  $k_l$  = computed submergence correction factor for flow over the upper, and lower embankment crests, respectively;  $w_u$  = width (parallel to flow direction) of the crest of the upper, and lower embankment, respectively.

When the bridge opening is submerged,  $C$  in Eqs. (C1) and (C11) is replaced by  $C'$  for orifice flow which is written as

$$C' = c_0 C \quad (C13)$$

in which  $c_0 = \begin{cases} 1.0 - (r - 0.09) & \text{if } 0.09 \leq r \leq 0.31 \\ 1.0 & \text{otherwise} \end{cases}$

$$(C14)$$

and  $r = (h_i - h_{br}) / d_i$   $(C15)$

I06    C       HCU    LU       WU       HCL    LL       WL  
I6A    ELEV    B

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
C	float	+	$C$ , bridge coefficient
HCU	float	+	$h_{cu}$ , elevation of the upper embankment crest
LU	float	+	$L_u$ , length of the upper embankment crest perpendicular to the flow direction including the length of bridge at elevation $h_{cu}$
WU	float	+	$w_u$ , width (parallel to flow direction) of the crest of the upper embankment
HCL	float	+	$h_{cl}$ , elevation of the lower embankment crest

LL	float	+	$L_l$ , length of the lower embankment crest perpendicular to the flow direction including the length of bridge at elevation $h_{cl}$
WL	float	+	$w_l$ , width (parallel to flow direction) of the crest of the lower embankment
ELEV	float	+	Elevation (ft)
B	float	0/+	Bridge opening B (ft) at Elevation ELEV

# I08, I8A, I8B

I08, I8A, I8B: Internal Flow Boundary Condition ----- Radial Gate

I08-optional, required only if KI = 8 in record IFB

I8A-optional, required after I08 if radial gate opening is given by time-opening table.

I8B-optional, required after I08 if radial gate opening is determined by water surface elevation.

The I08 record defines the bridge internal flow boundary condition. One I08 is used for a radial gate. Records I8A are used if the radial gate opening is input as a time-opening table. The record ID I8A is followed by one pair of time and opening data. The I8A record is repeated until the entire table is input. The I8B record is used if the gate opening is governed by the water surface elevation.

I8A	C	W	T	ZSP	TE	BE	HE	CW	GDIR
	GTYPE								
I8A	T2	ST2							
I8B	WSEOpen	WSECclose		OpenRate	CloseRate	MaxOpen	MinOpen		
	InitOpen								

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
C	float from 0.6-0.8)	+	$C$ , discharge coefficient (typically ranges
W	float m)	+	$W$ (ft or m), width of the gate spillway (ft or
T	float	+	$T$ (ft or m), Trunnion height (from spillway crest to trunnion pivot point)
ZSP	float	+	$Z_{sp}$ (ft or m), elevation of the spillway crest through the gate (ft or m)
TE	float 0.16)	+	$T_E$ , trunnion height exponent (typically about 0.16)
BE	float	+	$B_E$ , gate opening exponent (typically about 0.72)
HE	float	+	$H_E$ , head exponent (typically about 0.62)
CW	float	+	$C_W$ , weir coefficient for weir flow
GDIR	int	0/1 0	Gate direction Inline gate

		1	Lateral gate (i.e. flow is taken away from river)
GTYPE	int	0/1	Gate type
		0	Radial gate
		1	Sluice gate
T2	float	+	Time (hr)
ST2	float	0/+	$B$ (ft or m), gate opening at time T2
WSEOpen	float	+	Upstream water surface elevation at which gate begins to open (ft or m)
WSECclose	float	+	Upstream water surface elevation at which gate begins to close (ft or m)
OpenRate	float	+	Gate opening rate (ft/min or m/min)
CloseRate	float	+	Gate closing rate (ft/min or m/min)
MaxOpen	float	+	Maximum gate opening (ft or m)
MinOpen	float	+	Minimum gate opening (ft or m)
InitOpen	float	+	Initial gate opening (ft or m)

# Data Group 5. Lateral Flow Inputs

## LNF

**LNF: Lateral Flows ----- Number**

Required

The LNF record specifies the number of lateral flow inputs.

LNF            NKQF

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
NKQF	int	0/+	number of lateral flow inputs
		0	No lateral flows. Skip records LFL to LFD
		n	n lateral flows, repeat records LFL to LFD for n times

# LFL

## LFL: Lateral Flow Inputs ----- Location

Optional, required if NKQF > 0 in record LNF.

The LFL record specifies the location of the lateral flows. Records LFL and LFD should be skipped if NKQF = 0 in record LNF and should be repeated if NKQF >1 for each lateral flow.

LFL            X1QF            X2QF

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
X1QF	float	+	Start location (ft or m) of lateral flows. The location coordinate will be multiplied by the scaling factor XFACT in records YSL
X2QF	float	+	End location (ft or m) of lateral flows. If point lateral flow is simulated, X2QF=X1QF. The location coordinate will be multiplied by the scaling factor XFACT in records YSL

# LFD

## LFD: Lateral Flow Inputs ----- Time-Discharge Table

Optional, required if NKQF > 0 in record LNF.

The LFD record defines the lateral flow input as a time-discharge table. A lateral inflow is defined as positive and an outflow is defined as negative. One record is used for each time-discharge pair. The LFD record is repeated until the entire table is input. For steady flow, no interpolation of discharge is performed and the discharge becomes a step function in time. Changes to the discharge occur at the times input in the time-discharge table.. For unsteady flow, the discharges are interpolated for time between the specified T1 values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < T3_1$  the discharge for  $T3_1$  is used; if  $T > T3_n$  the discharge for  $T3_n$  is used, where  $n$  is the total last row of the table. If there is no discharge before the first value or after the last value, zero discharge should be added at the beginning or end of the table, respectively.

LFD            T3            ST3

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
T3	float	+	Time (hr)
ST3	float	-/0/+	Lateral flow discharge (cfs or cms) at time T3
		-	Lateral outflow
		+	Lateral inflow

## Data Group 6. Channel Geometry and Flow Characteristics

### NAM

**NAM:** Number and name of river

Required

The NAM record specifies the number and name of river. The river numbering must occur in sequential order. The river name may include spaces.

NAM            RNUM            RNAM

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
RNUM	INT	1+	River number
RNAM	CHAR		Name of River

# XIN

## XIN: Station ----- Initial Condition

Required

The XIN record specifies the initial condition at a station. The XIN records are only used for unsteady flow. Each station is identified by a set of several records: XIN, XST, XSP, XII/XIX, XLI/XLX, XBU, XBD, XBI/XBX, XFL, and XSL. Among the records, XII/XIX, XLI/XLX, XBU, and XBD are optional, and the others are required. These records are repeated for each station. The stations are entered in order, in the downstream direction, starting at the most upstream cross section.

XIN            TMP    ZDI    QDI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TMP	float		Not presently used
ZDI	float	0/+	Initial stage
		0	Initial stage is calculated from steady solution
QDI	float	0/+	Initial discharge
		0	Initial discharge is calculated from steady solution

# XST

## XST: Station ----- Location

Required

The XST record is used to define various cross section properties: its streamwise location, the modification to bed elevations, number of interpolated cross sections. This record also controls if the cross section data is updated during a hot start. A cold start means that the simulation starts from the initial condition. A hot start means that the simulation starts from the end of last simulation, whose results are saved in a binary file.

XST XT BEC NINTERP IHOTC

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
XT	float	0/+	Location of the station, i.e., its coordinate measured from a reference station location downstream (ft or m). The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
BEC	float	0/+	Cross section elevation adjustment factor, BEC, will be added to the given bed elevation across the channel at the present station
NINTERP	int	0/+	Interpolation number, NINTERP, this number of cross sections will be interpolated between the present cross section and the next downstream cross section
IHOTC	int	0	No action
		0/1	Option to restart the calculation with new cross section geometry. This data is ignored during cold start
		0	Use cross section geometry of last calculation during hot start
		1	Use new input of this cross section geometry during hot start

# XSP

## XSP: Station ----- Cross Section Geometry

Required

The XSP record is used to define the cross sectional geometry at the given station. The cross section is described by a set of coordinate pairs. Each coordinate pair contains a lateral location and a bed elevation. The set of data points for each cross section start from the left side of the channel, looking downstream, and progress towards the right-hand side. The number of the coordinate pairs in each XSP record may vary. However, each line is limited to 200 characters and one coordinate pair cannot be separately placed in two XSP records. XSP records are added until all coordinate pairs are input. If YZ = 0 in the YSL record, the cross section geometry must be input using bottom elevation and lateral location pairs instead of the lateral location and bottom elevation pairs as shown below.

XSP            CROSLOC    BOTTOM

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
CROSLOC	float	-/0/+	Lateral coordinate, measured from a reference point, of the data points that define the cross-sectional geometry at the current station (ft or m)
BOTTOM	float	-/0/+	Vertical coordinate (bottom elevation) of the data points that define the cross-section geometry at the current station (ft or m). The cross section elevation adjustment factor, BEC, in record XST is added to BOTTOM

# XII/XIX

## XII/XIX: Station ----- Ineffective Flow Area

Optional

The XII/XIN record is used to define the ineffective flow areas (areas where the conveyance is zero): their left and right extents (specified as an index or lateral coordinate), and water surface elevations under which the conveyance is zero. More than one ineffective flow area can be defined in a cross section. The ineffective area can be defined by either one of the records (XII or XIX), but not both.

XII	LOCL_DEAD	LOCR_DEAD	HDEAD
XIX	DEADL	DEADL	HDEAD

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_DEAD	int	+	Point index of left location of ineffective flow area
LOCR_DEAD	int	+	Point index of right location of ineffective flow area
DEADL	float	-/+	Lateral coordinate of left location of ineffective flow area
DEADR	float	-/+	Lateral coordinate of right location of ineffective flow area
HDEAD	float	-/+	Elevation (ft or m) until which the area is ineffective

# XPI / XPX

## XPI/XPX: Station ----- Permanent Ineffective Flow Area

Optional

The XPI/XPX record is used to define the permanent ineffective flow areas, their left and right extents (specified as an index or lateral coordinate), and upper elevations. When the water surface elevation is lower than the upper elevation, the area is ineffective. When the water surface elevation is higher than the upper elevations, the area about the elevation is effective and the area below the upper elevation is still ineffective. More than one permanent ineffective flow area can be defined in a cross section. The permanent ineffective area can be defined by either one of the records (XPI or XPX), but not by both.

XPI	LOCL_PDEAD	LOCR_PDEAD	HPDEAD
XPX	PDEADL	PDEADR	PHDEAD

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_PDEAD	int	+	Point index of left location of permanent inefficient flow area
LOCR_PDEAD	int	+	Point index of right location of permanent inefficient flow area
PDEADL	float	-/+	Lateral coordinate of left location of permanent inefficient flow area
PDEADR	float	-/+	Lateral coordinate of right location of permanent inefficient flow area
HPDEAD	float	-/+	Elevation (ft or m) until which the area is permanent inefficient (conveyance is zero)

# XLI/XLX

## XLI/XLX: Station ----- Dry Areas

Optional

The XLI/XLX record is used to define dry areas: their left and right extents (specified as an index or lateral coordinate), and water surface elevation under which the area is dry. More than one dry area can be defined in a cross section. The dry area can be defined by either of the records (XLI or XLX), but not by both. Dry areas can be used to represent levees.

XLI	LOCL_LEV	LOCR_LEV	HLEV
XLX	LEVEEL	LEVEER	HLEV

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_LEV	int	+	Point index of left location of dry area
LOCR_LEV	int	+	Point index of right location of dry area
LEVEEL	float	-/+/-	Lateral coordinate of left location of dry area
LEVEER	float	-/+/-	Lateral coordinate of right location of dry area
HLEV	float	-/+/-	Elevation (ft or m) until which the area is dry

# XBI/XBX

## XBI/XBX: Station ----- Blocked Areas

Optional

The XBI/XBX record is used to define blocked areas: their left and right extents (specified as an index or lateral coordinate), and the upper elevations. More than one blocked area can be defined in a cross section. The blocked area can be defined by either of the records (XBI or XBX), but not by both.

XBI	LOCL_BLOCK	LOCR_BLOCK	HBLOCK
XBX	BLOCKL	BLOCKR	HBLOCK

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_BLOCK	int	+	Point index of left location of blocked area
LOCR_BLOCK	int	+	Point index of right location of blocked area
BLOCKL	float	-/+	Lateral coordinate of left location of blocked area
BLOCKR	float	-/+	Lateral coordinate of right location of blocked area
HBLOCK	float	-/+	Elevation (ft or m) until which the area is blocked

# XRI/XRX

## XRI/XRX: Station ----- Rip Rap Locations

Optional

The XRI/XRX record is used to define areas of the cross section that have been protected with immovable bank protection such as riprap. The left and right extents (specified as an index or lateral coordinate) are user specified and the elevations of the protection is assumed to be at the elevation of the cross section points. More than one riprap area can be defined in a cross section. The riprap area can be defined by either of the records (XRI or XRX), but not by both. The areas protected by riprap are not allowed to erode.

XRI	LOCL_RIPRAP	LOCR_RIPRAP
XRX	RIPRAPL	RIPRAPR

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_RIPRAP	int	+ area	Point index of left location of riprap
LOCR_RIPRAP	int	+ area	Point index of right location of riprap
RIPRAPL	float	-/0/+	Lateral coordinate of left location of riprap area
RIPRAPR	float	-/0/+	Lateral coordinate of right location of riprap area

# XBU

## XBU: Station ----- Upstream Break Points

Optional

The XBU record is used to define the upstream break points. The break points are used to interpolate cross sections between two input cross sections. The number of upstream break points should be equal to that of downstream break points defined at the upstream cross section. Breakpoints are only used when cross sections are interpolated. The method of interpolation is similar to that performed in HEC-RAS. By default, there are 5 breakpoints defined: 2 for the endpoints, 2 for the overbank points and 1 for the channel thalweg.

XBU            LOCBPU(1:n)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCBPU	int	+	Point index of break point
n	int	+	Number of breakpoints

# XBD

## XBD: Station ----- Downstream Break Points

Optional

The XBD record is used to define the downstream break points. The break points are used to interpolate cross sections between two input cross section. The number of downstream break points should be equal to that of upstream break points defined at the downstream cross section. Breakpoints are only used when cross sections are interpolated. By default, there are 5 breakpoints defined: 2 for the endpoints, 2 for the overbank points and 1 for the channel thalweg.

XBD            LOCBPD(1:n)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCBPD	int	+	Point index of break point
n	int	+	Number of breakpoints

# **XRH**

## **XRH: Station ----- Roughness Coefficients.**

Required

The XRH record is used to define the roughness coefficients. The roughness coefficients are described by coordinate-coefficient pairs. The coordinates divides the cross sections into subchannels with different roughness coefficients. The coordinates must be given starting from the left side of the channel, looking downstream, and progress towards the right-hand side. The number of the pairs in each XSP record may vary. However, a coordinate pair cannot be separated in two XRH records.

XRH            XLOC\_LCOEF            LCOEF

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
XLOC_LCOEF	float	-/0/+	Lateral coordinate (ft or m) under which the roughness coefficient is defined in the pair
LCOEF	float	+	Roughness coefficient when the lateral coordinate is greater than XLOC_RCOEF

# XOI/XOX

**XOI/XOX:** Station ----- Bank Location

Required

The XBI/XBX record is used to define the overbank locations. The overbank points divide the cross section into a left floodplain, a main channel, and a right floodplain. If there is no floodplain on one side of the channel, the overbank location is set at the end point of the cross section.

XOI	LOCL_OB	LOCR_OB
XOX	BANKL	BANKR

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LOCL_OB	int	+	Point index of left overbank.
LOCR_OB	int	+	Point index of right overbank.
BANKL	float	-/0/+	Lateral coordinate of left overbank.
BANKR	float	-/0/+	Lateral coordinate of right overbank.

# XFL

## XFL: Station ----- Cross Section Energy Loss Coefficient

Required

The XFL record is used to define the energy loss coefficient at that cross section or downstream of that cross section.

XFL            KEXP            KCON

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KEXP	float	0/+	Local energy loss coefficient that accounts for energy losses due to flow expansion between this cross section and the one downstream
KCON	float	0/+	Local energy loss coefficient that accounts for energy losses due to flow contraction between this cross section and the one downstream

# XSL

## XSL: Station ----- Geo-Referenced Cross section positions

Required

The XSL record is used to define the Geo-Referenced location of the cross section. The data is entered in easting and northing data pairs. This data is not presently used by GSTAR-1D, but is listed as a data input so that the actual location of cross sections can be reference. A minimum of two data points must be entered, but there is no maximum. It is assumed that the station elevation data points occur along the geo-referenced points.

This is the end of flow input. This is the last data record required if there is no sediment simulation (NF = 0 in record YNR). If there is no sediment input then Data Groups 7 to 14 will be skipped.

XSL            XGIS    YGIS

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
XGIS	float	-/0/+	Easting location of cross section point
YGIS	float	-/0/+	Northing location of cross section point

# Data Group 7. Sediment Model Parameters

## YST

### YST: Sediment Solution Parameters

Required

The YST record is used to define the sediment solution parameters: the implicit factor for sediment transport solution, number of sediment time steps to perform during one flow computation, and frequency of angle of repose calculations.

If a river network is simulated, records YST to YSG are used for the entire river network, and records USB to CDI are specific to an individual river and should be repeated for each river.

YST            THETA            NTSEDF            NREPOSE

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
THETA	float	0-1	Implicit factor used in the sediment transport solution (usually set to 1)
NTSEDF	int	+	Number of sediment time steps to perform during one flow computation
NREPOSE	int	+	Bank adjustment is performed every <i>NREPOSE</i> time steps

# YSG

## YSG: Sediment Size Group

Required

YSG records are used to define the sediment size groups. The dry specific weight for individual size groups can also be defined in these records. The number of YSG records must equal the value of NF defined in record YNR (one YSG record is required for each size fraction), and the records must be ordered with increasing sediment sizes.

The lower bound for sand sizes is 0.0625 mm. If a lower mean particle size is given, the cohesive sediment transport methods will automatically be activated. For each size group, the program computes the geometric mean grain size as  $D_{mean} = \sqrt{DRU \times DRL}$ .

YSG            DRL    DRU    BDIN

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
DRL	float	+	Lower boundary of the particle size for this group (mm)
DRU	float	+	Upper boundary of the particle size for this group (mm)
BDIN	float	+	Dry specific weight or dry bulk density for the size fraction (lb/ft <sup>3</sup> or N/m <sup>3</sup> )
		0	Use the default dry specific weight (99.26 lb/ft <sup>3</sup> or 15580 N/m <sup>3</sup> )

# Data Group 8. Sediment Boundary Conditions

## USB

### USB: Upstream Sediment Boundary Condition

Required

The USB record specifies the upstream sediment boundary condition type.

If a river network is simulated, records YST to YSG are used for the entire river network, and records USB to CDI are specific to an individual river and should be repeated for each river.

USB            KUS

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
KUS	int	0/1/2/3/4	Type of upstream sediment boundary condition
upstream rivers		0	Junction, sediment input comes from
		1	Sediment transport formula
		2	Rating curve
		3	Table (flow, sediment discharge)
		4	Table (time, sediment discharge)

# **US0**

## **US0: Upstream Sediment Boundary Condition ----- Junction**

Optional, required only if KUS = 0 in record USB

The US0 record defines the upstream sediment boundary condition as junction. The sediment input at the upstream will come from the last cross section of upstream river. No variable is required.

US0

# US1

## US1: Upstream Sediment Boundary Condition ----- Sediment Transport Equation

Optional, required only if KUS = 1 in record US2

The US1 record is used when the upstream sediment input is calculated using a sediment transport equation, defined in record SEQ. The record ID is followed by a scaling factor  $a_s$ . The sediment discharge from sediment transport equation will be multiplied by  $a_s$ .

US1            AQRC

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
AQRC	float	+	Scaling Factor, $a_s$ . The sediment discharge from sediment transport equation will be multiplied by $a_s$

# US2

## US2: Upstream Sediment Boundary Condition ----- Rating Curve

Optional, required only if KUS = 2 in record USB

The US2 record defines the upstream flow boundary condition as a rating curve. The record ID is followed by two rating parameters  $a_s$ ,  $b_s$ . The sediment discharge (ton/day) is calculated as  $Q_x = a_s Q^{b_s}$ , where  $Q$  = flow discharge (cfs or cms).

US2            AQRC            BQRC

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
AQRC	float	+	Rating curve coefficient $a_s$
BQRC	float	0/+	Rating curve coefficient $b_s$

# US3

## US3: Upstream Sediment Boundary Condition ----- Flow-Sediment Discharge Table

Optional, required only if KUS = 3 in record USB

The US3 record defines the upstream sediment boundary condition as a flow-sediment discharge table. One record is used for each flow-sediment discharge pair. The US3 record is repeated until the entire table is input. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $Q < QI_1$  the sediment discharge for  $QI_1$  is used; if  $Q > QI_n$  the discharge for  $QI_n$  is used, where  $n$  is the last row of the table.

US3            QI            QSI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
QI	float	0/+	Flow rate (cfs or cms)
QSI	float	0/+	Sediment discharge (ton/day)

# US4

## US4: Upstream Sediment Boundary Condition ----- Time-Discharge Table

Optional, required only if KUS = 4 in record USB

The US4 record defines the upstream sediment boundary condition as a time-discharge table. One record is used for each time-discharge pair. The US4 record is repeated until the entire table is input. For steady flow, no interpolation of discharge is performed and the discharge becomes a step function in time. Changes to the discharge occur at the times input in the time-discharge table. For unsteady flow, the discharges are interpolated in time between the specified TSI values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < TSI_1$  the discharge for  $TSI_1$  is used; if  $T > TSI_n$  the discharge for  $TSI_n$  is used, where  $n$  is the last row of the table. If there is no sediment discharge before the first value or after the last value, a zero value should be added at the beginning or end of the table, respectively.

US4            TSI            QSI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TSI	float	0/+	Time (hr)
QSI	float	0/+	Sediment discharge (ton/day)

# USS

## USS: Upstream Sediment Boundary Condition ----- Sediment Size Distribution

Optional, required only if KUS = 2, 3, or 4 in record USB

The USS record defines the sediment size distribution at the flow discharge QIC. The size distributions are given from the finest to the coarsest size fractions. The sediment size distributions are interpolated for flow discharges between the specified  $QIN$  values. For values of the flow discharge outside of the table, no extrapolation is done; i.e., if  $Q < QIN_1$  the distribution for  $QIN_1$  is used; if  $Q > QIN_n$  the distribution for  $QIN_n$  is used, where  $n$  is the last row of the table.

USS            QIN            PISID(1:nf)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
QIN	float	+	Flow discharge (cfs or cms) at which sediment size distribution is given
PISID(1:nf)	float	+	Sediment size distribution at one flow discharge.
nf	in	+	Sediment size number defined in record YNR.

# Data Group 9. Lateral Sediment Inflows

## LNS

### LNS: Number of Lateral Sediment Inputs

Required

The LNF record specifies the number of lateral sediment inputs.

LNS            NKQS

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
NKQS	int	0/+	Number of lateral sediment input
		0	No lateral sediment input. Skip records LSL to LSD
		n	n lateral sediment input, Records LSL and LSD will be repeated n times

# LSL

## LSL: Location of Lateral Sediment Input

Optional, required if NKQS>0 in records LNS.

The LQL record specifies the stream location of the lateral sediment input. Records LSL to LSD should be skipped if NKQS = 0 in record LNS and should be repeated if NKQS >1 for each lateral sediment input.

LSL	X1QS	X2QS	LTYPE
-----	------	------	-------

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
X1QS	float	+	Starting location (ft or m) of the lateral sediment input. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
X2QS	float	+	End location (ft or m) of lateral sediment input. If point lateral sediment input is simulated, X2QS=X1QS. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
LTYPE	int condition.	2/3/4/5	Type of lateral flow input sediment boundary
		2	Rating curve
		3	Table (flow, sediment discharge)
		4	Table (time, sediment discharge)
		5	Table (time, sediment discharge for each size fraction)

# LS2

## LS2: Lateral Sediment Discharge – Rating Curve

Optional, required only if LTYPE = 2 in record LSL

The LS2 record defines the upstream flow boundary condition as a rating curve. The record ID is followed by two rating parameters  $a_s$  and  $b_s$ . The sediment discharge (ton/day) is calculated as  $Q_{x,lat} = a_s Q^{b_s}$ , where  $Q$  = flow discharge of lateral flow input (cfs or cms).

LS2            LAQRC            LBQRC

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
LAQRC	float	+	Rating curve coefficient $a_s$ for lateral flow input
LBQRC	float	0/+	Rating curve coefficient $b_s$ for lateral flow input

# LS3

## LS3: Lateral Sediment Discharge – Flow-Sediment Discharge Table

Optional, required only if LTYPE = 3 in record LSL

The LS3 record defines the upstream sediment boundary condition as a flow-sediment discharge table. One record is used for each flow-sediment discharge pair. The LS3 record is repeated until the entire table is input. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $Q_{lat} < QLI_1$  the sediment discharge for  $QLI_1$  is used; if  $Q_{lat} > QLI_n$  the discharge for  $QLI_n$  is used, where  $n$  is the last row of the table.

LS3            QLI    QSLI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
QLI	float	0/+	Flow rate (cfs or cms)
QSLI	float	0/+	Sediment discharge (ton/day)

# LS4

## LS4: Upstream Sediment Boundary Condition ----- Time-Discharge Table

Optional, required only if LTYPE = 4 in record LSL

The LS4 record defines the upstream sediment boundary condition as a time-discharge table. One record is used for each time-discharge pair. The LS4 record is repeated until the entire table is input. For steady flow, no interpolation of discharge is performed and the discharge becomes a step function in time. Changes to the discharge occur at the times input in the time-discharge table. For unsteady flow, the discharges are interpolated in time between the specified TSLI values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < TSLI_1$  the discharge for  $TSLI_1$  is used; if  $T > TSLI_n$  the discharge for  $TSLI_n$  is used, where  $n$  is the last row of the table. If there is no sediment discharge before the first value or after the last value, a zero value should be added at the beginning or end of the table, respectively.

LS4            TSLI    QSLI

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TSLI	float	0/+	Time (hr)
QSLI	float	0/+	Sediment discharge (ton/day)

# LS5

## LS5: Upstream Sediment Boundary Condition ----- Time-Discharge Table for Each Size Fraction

Optional, required only if LTYPE = 5 in record LSL

The LS5 record defines the upstream sediment boundary condition as a time-discharge table. One record is used for each time-discharge pair. The LS5 record is repeated until the entire table is input. For steady flow, no interpolation of discharge is performed and the discharge becomes a step function in time. Changes to the discharge occur at the times input in the time-discharge table. For unsteady flow, the discharges are interpolated in time between the specified TSI values. For values of the discharge outside of the table, no extrapolation is done; i.e., if  $T < TSLI_1$  the discharge for  $TSLI_1$  is used; if  $T > TSLI_n$  the discharge for  $TSLI_n$  is used, where  $n$  is the last row of the table. If there is no sediment discharge before the first value or after the last value, a zero value should be added at the beginning or end of the table, respectively.

US4            TSLI    QSLI(1:nf)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TSI	float	0/+	Time (hr)
QSI(1:nf)	float	0/+	Sediment discharge (ton/day) for each size fraction
nf	int	+	Sediment size number defined in record YNR

# LSS

## LSS: Lateral Sediment Discharge Sediment Size Distribution

Optional, required only if LTYPE = 2, 3, or 4 in record LSL

The LSS record defines the sediment size distribution at the flow discharge QIC. The size distributions are given in order from the finest to the coarsest size fractions. The sediment size distributions are interpolated for flow discharges between the specified  $QIN$  values. For values of the flow discharge outside of the table, no extrapolation is done; i.e., if  $Q < QIN_1$  the distribution for  $QIN_1$  is used; if  $Q > QIN_n$  the distribution for  $QIN_n$  is used, where  $n$  is the last row of the table.

LSS            QLIN            PISIDL(1:nf)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
QLIN	float	+	Flow discharge (cfs or cms) at which sediment size distribution is given
PISIDL(1:nf)	float	+	Sediment size distribution at one flow discharge
nf	in	+	Sediment size number defined in record YNR

# Data Group 10. Sediment Bed Material

## BT0/BT1/BT2

BT0/BT1/BT2: Bed Properties ----- Location of Thickness

Required if NLAY > 2

The BT0/BT1/BT2 record specifies the locations where the bed layer thicknesses (see Figure 3.1) are given. If the record BT0 is used, the bed thicknesses will be given at each station listed in XST records and no variable is required. If the record BT1 is used, the bed thicknesses will be given at specific stations in the form of station indexes. If the record BT2 is used, the bed thicknesses will be given at specific locations in the form of streamwise coordinates (x). Both location indexes and longitudinal coordinates can be given in ascending or descending order. Additional BT1/BT2 records can be used until all locations are defined.

BT0

BT1 II(1:nt)

BT2 XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where bed thicknesses for each layer will be given
XC	float	0/+	Station Coordinates (ft or m) where bed thicknesses for each layer will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where bed thicknesses for each layer will be given

# BTT

## BTT: Bed Properties ----- Thickness

Required if NLAY > 2

The BTT specifies the bed layer thickness at each bed layer (see Figure 3.1) where location is given at the BT0/BT1/BT2 record. If the record BT0 is used, the bed thicknesses are given at each station listed in XST records. If the record BT1/BT2 is given, the bed thicknesses are given at specific locations. The record should be repeated nt times, where nt is the number of locations specified in the BT0/BT1/BT2 record. Since the first layer is always active layer, its thickness is not given in this record. The input for second layer thickness includes both first layer and second layer thicknesses used in the program. The last layer's thickness is always considered infinite and is not input. Therefore, this record is only required if more than 2 layers are being considered in the model.

BTT            THICK(2:nlay-1)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
THICK	float	+	Bed layer thickness at given locations

# BP0/BP1/BP2

## BP0/BP1/BP2: Bed Properties ----- Location of Size Fractions

One of the three is required

The BP0/BP1/BP2 record specifies the locations where the sediment size fractions at each bed layer are given. If the record BP0 is used, the size fractions will be given at each station listed in XST records and no variable is required. If the record BP1 is used, the size fractions will be given at specific stations in the form of station indexes. If the record BP2 is used, the size fractions will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates can be given in ascending or descending order. Additional BP1/BP2 records can be used until all locations are input.

BP0

BP1 II(1:nt)

BP2 XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where sediment size fractions for each layer will be given
XC	float	0/+	Station Coordinate (ft or m) where sediment size fraction for each layer will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where sediment size fractions will be given

# BPL

## BPL: Bed Properties ----- Sediment Size Fractions

Required.

The BPL record specifies the fractions within each sediment size class at each bed layer at the locations given in the BP0/BP1/BP2 record. If the record BP0 is used, the sediment size class fractions are given at each station given in XST records. If the record BP1/BP2 is given, the sediment size class fractions are given at specific locations. The record is repeated for layer number 1 until all the locations are given. Then, this process is repeated for layers 2 to NLAY. The bed fractions for the first layer will be used for the active layer.

BPL            PTMP(1:nf)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
PTMP	float	+	sediment size fractions

# Data Group 11. Water Temperature

## TMP

### TMP: Water Temperature

Required

The TMP record is used to enter the water temperature of the study reach. A time-temperature table is input in this record. The TMP record is repeated until the entire table is input. The program obtains the temperature at a specific time by interpolation. The temperatures are interpolated between the given times. For times outside of the given times, no extrapolation is done; i.e., if  $T < TIME_1$ , the temperatures for  $TIME_1$  is used; if  $T > TIME_n$ , the temperatures for  $TIME_n$  is used, where  $n$  is the last row of the table.

TMP            TIME            TMP

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
TIME	float	+	Time (hr)
TMP	float	-/0/+	Temperature (F or C)

# Data Group 12. Erosion and Deposition Limits

## FI0/FI1/FI2

### FI0/FI1/FI2: Bed Limitation Locations

One of three required.

The FI0/FI1/FI2 record specifies the locations where the limits of scour and deposition are defined. These limits correspond to restrictions, geological or man-made, to deposition and/or scour. If the record FI0 is used, the limits will be given at each station listed in XST records and no variable is required. If the record FI1 is used, the limits will be given at specific stations in the form of station indexes. If the record FI2 is used, the limits will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates are given in ascending or descending order. Additional FI1/FI2 records are used until all locations are defined.

FI0

FI1            II(1:nt)  
FI2            XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where width and bed elevation limits will be given
XC	float	0/+	Station Coordinates (ft or m) where width and bed elevation limits will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where width and bed elevation limits will be given

# FIM

## FIM: Bed Limitations

Optional.

The FIM specifies the vertical limits of scour and deposition at the locations specified in the FI0/FI1/FI2 record. If the record FI0 is used, the vertical and horizontal limits are given at each station listed in XST records. If the record FI1/FI2 is given, the width vertical and horizontal limits are given at specific locations. The record should be repeated until all the stations are given. The table is interpolated for stations within the table. For stations outside of the table, no extrapolation is done. If a specific location is not inside the range of given locations, the first or last of the limits in the table is used, depending on if the specific location is upstream or downstream of the range. Very large or very small numbers are used if scour or deposition is not constrained.

FIM	CROSMIN_E	CROSMAX_E	CROSMIN_D
	CROSMAX_D	BOTMIN	BOTMAX

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
CROSMIN_E	float	-/0/+	Lateral location (ft or m) beyond which no erosion is allowed. This location corresponds to the left-hand side restriction, looking downstream
CROSMAX_E	float	-/0/+	Lateral location (ft or m) beyond which no erosion is allowed. This location corresponds to the right-hand side restriction, looking downstream
CROSMIN_D	float	-/0/+	Lateral location (ft or m) beyond which no deposition is allowed. This location corresponds to the left-hand side restriction, looking downstream
CROSMAX_D	float	-/0/+	Lateral location (ft or m) beyond which no deposition is allowed. This location corresponds to the right-hand side restriction, looking downstream
BOTMIN	float	-/0/+	Limit for scour in the vertical direction. No scour is allowed beyond this bottom elevation (ft or m)

BOTMAX	float	-/0/+	Limit for deposition in the vertical direction. No deposition is allowed beyond this bottom elevation (ft or m)
--------	-------	-------	---

# FIW

## FIW: Bed Limitations and Erosion Limits Defined by Flow

Optional.

The FIW specifies the vertical limits of scour and deposition at the locations specified in the FI0/FI1/FI2 record. It is also used to specify the erosion width. If the record FI0 is used, the vertical and horizontal limits are given at each station listed in XST records. If the record FI1/FI2 is given, the width vertical and horizontal limits are given at specific locations. The record should be repeated until all the stations are given. The table is interpolated for stations within the table. For stations outside of the table, no extrapolation is done. If a specific location is not inside the range of given locations, the first or last of the limits in the table is used, depending on if the specific location is upstream or downstream of the range. Very large or very small numbers are used if scour or deposition is not constrained. The erosion width,  $W_e$ , is determined by:  $W_e = aQ^b$ , where  $a$  and  $b$  are user defined values.

FIM	CROSMIN_E	CROSMAX_E	CROSMIN_D
	CROSMAX_D	BOTMIN	BOTMAX ACONST BCONST

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
CROSMIN_E	float	-/0/+	Lateral location (ft or m) beyond which no erosion is allowed. This location corresponds to the left-hand side restriction, looking downstream
CROSMAX_E	float	-/0/+	Lateral location (ft or m) beyond which no erosion is allowed. This location corresponds to the right-hand side restriction, looking downstream
CROSMIN_D	float	-/0/+	Lateral location (ft or m) beyond which no deposition is allowed. This location corresponds to the left-hand side restriction, looking downstream
CROSMAX_D	float	-/0/+	Lateral location (ft or m) beyond which no deposition is allowed. This location corresponds to the right-hand side restriction, looking downstream
BOTMIN	float	-/0/+	Limit for scour in the vertical direction. No erosion is allowed beyond this bottom elevation (ft or m)

BOTMAX	float	-/0/+	Limit for deposition in the vertical direction. No deposition is allowed beyond this bottom elevation (ft or m)
ACONST	float negative, then greater than wetted width.	-/+	constant in erosion width equation. If erosion width always is
BCONST	float	+	exponent in erosion width equation.

# Data Group 13. Sediment Transport Parameters

## STU

### STU: Number of Sub-channels and width adjustments

Required

The STU record is used to define the total number of subchannels that are used in sediment transport simulations. If KFLP = 1 in record YFP, then NSTUBE should be 3.

STU           NSTUBE       BFRAC

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
NSTUBE	int	1-3	Number of subchannels
WFRAC	float	0~1	Not presently used. Will be used to control the type of widening implemented
BFRAC	float	0~1	Minimum weight given to bank adjustment relative to bed adjustment. Default is 0.

# **SMN**

## **SMN: Sediment Properties ----- Minimization Option**

Required.

The record SMN specifies the type of minimization routine performed.

SMN            IMIN    ILENGTH

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
IMIN	int	0/1/2/3+	Minimization option
		0	No minimization
		1	minimization of conveyance
		2	minimization of total stream power (not presently supported)
		3	minimization of energy slope
ILENGTH	int	0/+	Reserved for future options

# SEQ

## SEQ: Sediment Transport Equation

Required

The SEQ record selects the sediment transport equation used to compute sediment carrying capacities for non-cohesive sediment.

SEQ            ISED

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
ISED	int	+	Variable to choose the non-cohesive sediment transport equation used to compute sediment carrying capacity
		1	Meyer-Peter and Muller's method
		2	Laursen method
		3	Toffaleti's method
		4	England and Hansen's method
		5	Ackers and White's 1973 method
		6	Yang's 1973 sand and 1984 gravel formulas
		7	Yang's 1979 sand and 1984 gravel formulas
		8	Parker's method using Einstein's method to correct shear stress
		9	Yang's 1996 modified formula for Yellow River
		10	Ackers and White's method with revised (1990) coefficients
		11	Debouy's method
		12	Laursen-Madden method
		13	Revised Brownlie method
		14	Parker's method for bed load without shear stress correction

# **SA0/SA1/SA2**

## **SA0/SA1/SA2: Sediment Transport ----- Location for Sediment Transport Properties Input**

Required one of three.

The SA0/SA1/SA2 record specifies the locations where the SAT record for sediment transport properties is given. If the record SA0 is used, the SAT record will be given at each station listed in XST records and no variable is required. If the record SA1 is used, the SAT record will be given at specific stations in the form of station indexes. If the record SA2 is used, the SAT record will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates are given in ascending or descending order. Additional SA1/SA2 records are used until all locations are input.

SA0

SA1            II(1:nt)

SA2            XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where the SAT record will be given
XC	float	0/+	Station Coordinates (ft or m) where the SAT record will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where the SAT record will be given

# SAT

## SAT: Sediment Transport ----- Properties

Required.

The SAT specifies the sediment transport properties at each location given in the SA0/SA1/SA2 record. These properties include: the sediment angle of repose, the coefficient of active layer thickness, the recovery factors for deposition and scour, the transverse and longitudinal dispersion coefficients, the weight given to the bed load during transfer to the sublayer, and coefficient of secondary flow. If the record SA0 is used, the sediment transport properties are given at each station given in XST records. If the record SA1/SA2 is used, the sediment transport properties are given at specific locations. The record should be repeated until all the stations are given.

SAT ANGLE1 ANGLE2 NALT ALPHAD ALPHAS BLENGTH WTDEP  
DLONG DTRANS

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
ANGLE1	float	+	Angle of repose of sediment at and above water
ANGLE2	float	+	Angle of repose of sediment below water
NALT	float	+	A user-specified positive multiplication factor for defining the thickness of active layer given as NALT*D(NF), where D(NF) is the geometric mean sediment size of the largest size fraction of record
		0	Use the default active layer thickness of 14*D(NF)
ALPHAD	float	0/+	Recovery factor for deposition
		0	Default value 0.25
ALPHAS	float	0/+	Recovery factor for scour
		0	Default value 1.0
BLENGTH	float	0/+	Bedload adaptation length (ft or m)
WTDEP	float	0 ~ 1	Weight given to bed load fractions for transfer of material from surface to subsurface layer during deposition ( $\chi$ in equation 3.88)

DLONG	float	0/+	Longitudinal dispersion coefficient (used if ISOLVES = 2)
DTRANS	float	0/+	Transverse dispersion coefficient (not currently used)

# Data Group 14. Cohesive Sediment Parameters

## CS0/CS1/CS2

### CS0/CS1/CS2: Cohesive Sediment Deposition ----- Locations

One of the three is required if cohesive sediment is present

The CS0/CS1/CS2 record specifies the locations where the cohesive sediment deposition parameters are given. If the record CS0 is used, cohesive sediment deposition parameters will be given at each station listed in XST records and no variable is required. If the record CS1 is used, cohesive sediment deposition parameters will be given at specific stations in the form of station indexes. If the record CS2 is used, cohesive sediment deposition parameters will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates can be given in ascending or descending order. Additional CS1/CS2 records can be used until all locations are input.

CS0

CS1            II(1:nt)

CS2            XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where cohesive sediment deposition parameters will be given
XC	float	0/+	Station Coordinate (ft or m) where cohesive sediment deposition parameters will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where cohesive sediment deposition parameters will be given

# CSD

## CSD: Cohesive Sediment Deposition ----- Parameters

Required only if cohesive sediment is present

The CSD record specifies the critical shear stress for cohesive sediment deposition, equilibrium sediment concentration during partial deposition, and the threshold value for the percentage of clay in the bed composition above which the erosion rates of gravels, sands, and silts are limited by the erosion rate of clay. These parameters are given at locations defined in the CS0/CS1/CS2 record.

The CSD record to CDI records are used in the cohesive sediment (clay and silt) transport model. If a sediment size group has a geometric mean grain size lower than 0.0625 mm, the cohesive sediment transport methods will be used to predict for the transport for those size groups. The equation specified in record SEQ record will be used for the remaining size groups. If silt and/or clay sizes are not present, these records should not be given.

CSD	STDEP_F	STDEP_P	CONCEQ	ER_LIM
-----	---------	---------	--------	--------

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
STDEP_F	float	+	Critical shear stress for full deposition of clay and silt (lb/ft <sup>2</sup> or N/m <sup>2</sup> )
STDEP_P	float	+	Critical shear stress for partial deposition of clay and silt (lb/ft <sup>2</sup> or N/m <sup>2</sup> )
CONCEQ	float	+	Equilibrium sediment concentration during partial deposition. (g/l)
ER_LIM	float	0~1.	Threshold value for the fraction of clay in the bed composition above which the erosion rates of gravels, sands, and silts are limited to the erosion rate of clay

# CE0/CE1/CE2

## CE0/CE1/CE2: Cohesive Sediment Erosion ----- Locations

One of the three is required if cohesive sediment is present

The CE0/CE1/CE2 record specifies the locations where the cohesive sediment erosion parameters are given. If the record CE0 is used, cohesive sediment erosion parameters will be given at each station listed in XST records and no variable is required. If the record CE1 is used, cohesive sediment erosion parameters will be given at specific stations in the form of station indexes. If the record CE2 is used, cohesive sediment erosion parameters will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates can be given in ascending or descending order. Additional CE1/CE2 records can be used until all locations are input.

CE0

CE1 II(1:nt)

CE2 XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where cohesive sediment erosion parameters will be given
XC	float	0/+	Station Coordinate (ft or m) where cohesive sediment erosion parameters will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where cohesive sediment erosion parameters will be given

# CER

## CER: Cohesive Sediment Erosion ----- Parameters

Required only if cohesive sediment is present.

The CER record specifies parameters for cohesive sediment erosions. If 4 parameters are used, the critical shear stress of the surface erosion, surface erosion rate, the critical shear stress of the mass erosion, and mass erosion rate are given. If 8 parameters are used, cohesive sediment transport parameters are calculated from the wet bulk density,  $\rho_b$ . The critical shear stress of surface erosion is calculated as  $\tau_{se}^c = a_{se}(\rho_b - \rho_l)^{b_{se}} + c_{se}$ , the surface erosion rate is calculated as  $\log_{10}(100M_{se}/d_{se}) = 0.23\exp(\frac{0.198}{\rho_b - 1.0023})$ , the critical shear stress of mass erosion is calculated as  $\tau_{me}^c = a_{me}\rho_b + b_{me}$ , and the mass erosion rate is calculated as  $\log_{10}(100M_{me}/d_{me}) = 0.23\exp(\frac{0.198}{\rho_b - 1.0023})$ . The variables are defined in the input table.

CER	STPERO	ER_STME	STMERO	ER_MASS
CER	ASE BSE	CSE RO_LSE	DSE	AME BME DME

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
STPERO	float	+	$\tau_{se}^c$ , critical shear stress of surface erosion of clay and silt ( $\text{lb}/\text{ft}^2$ or $\text{N}/\text{m}^2$ )
ER_STME	float	+	$P_{se}$ , surface erosion constant ( $\text{lb}/\text{ft}^2/\text{hr}$ or $\text{kg}/\text{m}^2/\text{hr}$ )
STMERO	float	+	$\tau_{me}^c$ , critical shear stress of cohesive sediment mass erosion ( $\text{lb}/\text{ft}^2$ or $\text{N}/\text{m}^2$ )
ER_MASS	float	+	$P_{me}$ , mass erosion constant ( $\text{lb}/\text{ft}^2/\text{hr}$ or $\text{kg}/\text{m}^2/\text{hr}$ )
ASE	float	+	$a_{se}$ , coefficient used to calculate critical shear
		0	Default value (0.0807 for English Units and 0.883 for SI Units)
BSE	float	+	$b_{se}$ , coefficient used to calculate critical shear
		0	Default value (0.20 for both units)
CSE	float	+	$c_{se}$ , coefficient ( $\text{lb}/\text{ft}^3$ or $\text{g}/\text{cm}^3$ ) used to calculate critical shear
		0	Default value (0.001045 for English Units and 0.005 for SI Units)

RO_LSE	float	+	$\rho_l$ , coefficient used to calculate critical shear Default value (66.4lb/ft <sup>3</sup> or 1.065g/cm <sup>3</sup> )
DSE	float	+	$d_{se}$ , coefficient used to calculate surface erosion constant. Default value (1.0)
AME	float	+	$a_{me}$ , coefficient in calculating critical shear default value (0.00329 for English Units and 0.208for SI Uints)
BSE	float	-	$b_{me}$ , coefficient in calculating critical shear Default value (-0.208 for English Units and -9.934 for SI Uints)
DME	float	+	$d_{me}$ , coefficient used to calculate the mass erosion constant. Default value (10.0)
		0	

# CF0 / CF1

## CF0/CF1: Cohesive Sediment ----- Fall Velocity

Required one of the two only if cohesive sediment is present.

The CF0/CF1 record specifies the relationship between the fall velocity and sediment concentration. If the CF0 record is used, a set of default values are used. If the CF1 record is used, the user needs to input four fall velocities at four specific sediment concentrations.

CF0            FVFORM

CF1            C1     V1     C2     V2     C3     V3     C4     V4

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
FVFORM	INT	+	Default material of cohesive sediment determining the fall velocity
		1	program default for KAOLINITE
		4	program default for SEVERN River
C1	float	+	Cohesive sediment concentration (g/l)
V1	float	+	Cohesive sediment fall velocity (mm/s) at concentration C1
C2	float	+	Cohesive sediment concentration (g/l)
V2	float	+	Cohesive sediment fall velocity (mm/s) at concentration C2
C3	float	+	Cohesive sediment concentration (g/l)
V3	float	+	Cohesive sediment fall velocity (mm/s) at concentration C3
C4	float	+	Cohesive sediment concentration (g/l)
V4	float	+	Cohesive sediment fall velocity (mm/s) at concentration C4

# CSC

## CSC: Cohesive Sediment ----- Consolidation

Required only if cohesive sediment is present

The CSC record specifies the consolidation parameters of cohesive sediment. The consolidation coefficient is computed from the user input of initial dry bulk density  $\rho_i$ , fully consolidated density  $\rho_f$ , and density  $\rho_e$  at the reference time  $t_e$ .

All densities are dry bulk densities.

CSC            DENSC\_I        DENSC\_F        DENSC\_E        TIME\_E

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
DENSC_I	float	+	Initial (fresh deposited) sediment dry bulk density (lb/ft <sup>3</sup> or kg/m <sup>3</sup> )
DENSC_F	float	+	Fully consolidated sediment dry bulk density (lb/ft <sup>3</sup> or kg/m <sup>3</sup> )
DENSC_E	float	+	Reference sediment dry bulk density at reference time TIME_E (lb/ft <sup>3</sup> or kg/m <sup>3</sup> )
TIME_E	float	+	Reference time (hr) at which the cohesive sediment dry bulk density DENSC_E is known

# CD0 / CD1 / CD2

## CD0/CD1/CD2: Cohesive Sediment ----- Location of Cohesive Sediment Density in Bed

One of three is required only if cohesive sediment is present.

The CD0/CD1/CD2 record specifies the locations where the cohesive sediment density in the bed is given. If the record CD0 is used, the cohesive sediment density will be given at each station listed in the XST records and no variable is required. If the record CD1 is used, the cohesive sediment density will be given at specific stations in the form of station indexes. If the record CD2 is used, the cohesive sediment density will be given at specific locations in the form of longitudinal coordinates (x). Both location indexes and longitudinal coordinates can be given in ascending or descending order. Additional CD1/CD2 records are used until all data are input.

CD0

CD1            II(1:nt)

CD2            XC(1:nt)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
II	int	+	Station index where cohesive sediment density will be given
XC	float	0/+	Station Coordinates (ft or m) where cohesive sediment density will be given. The location coordinate will be multiplied by the scaling factor XFACT in the record YSL
nt	int	+	Total number of stations where cohesive sediment dry bulk density will be given

# CDI

## CDI: Cohesive Sediment ----- Cohesive Sediment Dry Bulk Density in Bed

Required.

The CDI specifies the cohesive sediment dry bulk density at each bed layer at the locations given in the CD0/CD1/CD2 record. If the record CD0 is used, the cohesive sediment density is given at each station given in XST records. If the record CD1 or CD2 is given, the cohesive sediment density is given at specific locations. The record should be repeated until all the stations or locations are given. Since the first layer is the active layer, its cohesive sediment density is not given in this record. The input for second layer cohesive sediment density will be used for the density of both the first and second layers. The cohesive sediment dry bulk density ( $\rho_d$ ) is input in this record.

CDI              DENSITYCLAY0(2:nlay)

<u>Variable</u>	<u>Type</u>	<u>Value</u>	<u>Description</u>
DENSITYCLAY0	float	+	Dry bulk density of cohesive sediment transport from layer 2 to the bottom layer (nlay)
Nlay	int	2+	Number of bed layers

# **END**

**END: End of Input**

Required.

The record END is required at the end of the input data file to terminate the data input operations. No variable is required.

END

## **APPENDIX D**

### **EXAMPLE APPLICATIONS**

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# EXAMPLE 1 TRAPEZOID CHANNEL

This example shows a GSTAR-1D data file set-up for a simple trapezoid channel with sediment transport. A 5000-ft long trapezoid channel with bottom width of 200 ft and side slopes of 1V:2H is used. The channel slope is 0.001. The water discharge is 14,900 cfs and the downstream water surface elevation is set at normal depth. The upstream and downstream cross sections were input and then 9 cross sections were interpolated between them.

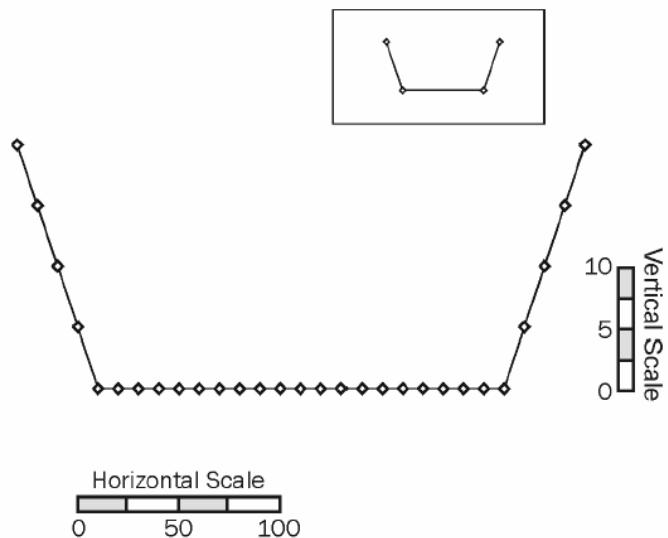


Figure D1.1 Sketch showing the discretization points used in the cross section template to define the channel. The smaller insert shows an equivalent cross section using the minimum possible number of discretisation points.

The upstream and downstream cross section use 29 points, as shown in Figure D1.1. The cross sections are input in (z, y) order and the elevation above datum is set using variable BEC in record XST.

The input sediment load is 48420 ton/day and 11 sediment sizes are used ranging from silt to small cobble. Incoming sediment size distribution is given in record USS. Two bed layers (one active layer and one inactive layer) are used. Only inactive layer thickness is input and the active layer thickness is calculated with input data NALT in record SAT. Bed size distributions are set using BLP records.

## D1.1 Input data file (Example1.txt)

The files shown in this and the next section are part of the main GSTAR-1D distribution package. They can be found under directory Example1.

```
YTT      GSTAR-1D version 1.1  Example data file for Appendix D of user's manual.
YTT      Trapezoidal channel with sediment transport.
YTT ****
*** NOTE: this is a datafile to be used as an example of input data as it ***
*** might be used in a GSTAR-1D version 1.0 simulation. It represents a ***
*** fictitious case and it should be viewed as such. It should not be used ***
*** for any other purpose without appropriate verification and validation. ***
*** -----
*** Problem Description: Trapezoidal channel with sediment transport. ***
*** Data Filename: trapzoid.data ***
*** Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m). ***
*** Side Slopes: 1V:2H ***
*** Channel Slope (s): 0.001 ***
*** Number of Stations: 21 equally spaced at 250 ft (76.2 m). ***
*** -----
****

****      nriv      nf      nlay
YNR      1        11      2
****      isolve    isolves     EPSY       F1      XFACT      METRIC      YZ
YSL      1        1  1.00E-04      1        1          0          0
****      KFLP      qmin
YFP      0        0
****      THE      iHotSt
YTM      2400      0
****      TDT      DT      DTPLT      xcplt
YDT      0        1      2400      1
****      Start of River 1
****      KU(J)
UFB      2
****      T1      ST1
U02      0      14900
U02      2400      14900
DFB      3
****      TN      SLFI
D03      0      1010
D03      2400      1010
****      # int. BC
INF      0
****      NKQF(J) non-point flow source
LNF      0
****      FLDST      ZDI      QDI -----cross      section      1
XIN      0        0        0
****      xt      bec      ninterp      iHotC      xc      spac      500slope =      0.001
XST      5000      5        9        0
****      station      elevation      data
XSP      1020      0      1015      10      1010      20      1005      30      1000      40
XSP      1000      50      1000      60      1000      70      1000      80      1000      90
XSP      1000      100      1000      110      1000      120      1000      130      1000      140
XSP      1000      150      1000      160      1000      170      1000      180      1000      190
XSP      1000      200      1000      210      1000      220      1000      230      1000      240
XSP      1005      250      1010      260      1015      270      1020      280
****      xloc_rcoef      rcoef
XRH      40      0.03      240      0.03      280      0.03
****      bankl      bankr
XOX      0      280
****      KEXP      KCON
XFL      0.3      0.1
****      xl      yl      xr      yr
XSL      5000      0      5000      280
```

```

***      FLDST      ZDI      QDI -----cross    section      10
XIN      0          0          0
***      xt        bec      ninterp      iHotC
XST      0.0        0          0          0
***      station elevation      data
XSP      1020       0          1015       10      1010       20      1005       30      1000       40
XSP      1000       50         1000       60      1000       70      1000       80      1000       90
XSP      1000       100        1000       110     1000       120     1000       130     1000       140
XSP      1000       150        1000       160     1000       170     1000       180     1000       190
XSP      1000       200        1000       210     1000       220     1000       230     1000       240
XSP      1005       250        1010       260     1015       270     1020       280
***      xloc_rcoef      rcoef
XRH      40          0.03      240       0.03      280       0.03
***
***      bankl      bankr
XOK      0          280
***      KEXP      KCON
XFL      0.3        0.1
***      xl        yl      xr      yr
XSL      0          0          0       280
***      End of River 1
***      Start Sediment Transport Input
***      theta      ntsedf      nresponse
YST      1          2          1
***      drl      dru      bdin
YSG      0.01      0.0625      0          ! silt      0.03
YSG      0.0625      0.25      0          ! fsnd      0.13
YSG      0.25        0.5       0          ! msnd      0.35
YSG      0.5          1       0          ! csnd      0.71
YSG      1          2       0          ! vcsnd      1.41
YSG      2          4       0          ! vfgrv      2.83
YSG      4          8       0          ! fgrv      5.66
YSG      8          16      0          ! mgrv      11.31
YSG      16         32      0          ! cgrv      22.63
YSG      32         64      0          ! vcgrv      45.25
YSG      64        128      0          ! scob      90.51
***      Start of River 1            3
***      nts
USB      4
***      TSI      QSI
US4      0      4.85E+04
US4      1000      4.85E+04
US4      2000      4.85E+04
***      QI      PISED
***      1          2          3          4          5          6          7          8
9      10         11
USS      0.0000      0.0000      0.5515      0.1244      0.1449      0.1567      0.0034      0.0054      0.0064
0.0066      0.0006      0.0000
***      NKQS(J) non-point flow source
LNS      0
***      ii
BP1      1
***      PTMP
***      Layer      2
***      silt/clay vfs      fs      s      cs      vcs      vfg      fg      g
cg      vcg
BPL      0          0.104      0.083      0.13      0.146      0.156      0.141      0.109
0.086      0.032      0.013
***      ttin      temp
TMP      0      70.00
***      Erosion      and      Deposition Limits
FI2      0
***      crosmi_n_e      crosmax_n_e      crosmi_d      crosmax_d      botmin      botmax
FIM      -99999      99999      -99999      99999      0      99999
***      nstube      wfrac
STU      1          0.8
***      imin      ilength
SMN      0          0
***      ised
SEQ      6
***      xc

```

```

SA2          0      5000
*** angle1(abangle2(benalt    alphad   alphas   blength   wt dep   dlong   dtrans
SAT         90      90       10      0.25      1       0       0       0       0       0
SAT         90      90       10      0.25      1       0       0       0       0       0
***      ii
CS2          0
*** stdep_f stdep_p   concEq   er_lim
CSD        0.02     0.02      1       0.1
***      ii
CE2          0
*** stpero er_stme   stmero   er_mass
CER        0.04     0.2500    2.84     1.07
*** fall velocity
CF0        1.00
*** densC_I densC_f  densC_e   time_e
CSC        77.98    101.30    81.86    1000.00
***      xc
CD2          0
*** densityClay0
CDI        101.30
*** end message
END

```

## D1.2 Output data file

Most lines in the output files are too long to be fitted into the width of the paper. In the following output data files, new lines are started with a black dot for easier reading. Sediment variables are not calculated at the initial time step.

### D1.2.1 Main Output File (example1\_out.dat)

This file summarizes the dimensions that are used in the model. The total number of cross sections used in the simulation is more than the original input cross sections and interpolated cross sections because one extra cross section for each river is used for unsteady flow calculation. The maximum number of points in each cross section is two times of the original input due to cross section interpolation. The input data is also echoed in output, which is not printed here due to space limit. When input errors occur, the users should first check this file for possible warnings.

```

• **** *SUMMARY*****
•                               Number of rivers=      1
•                               Number of sediment class= 11
•                               Number of sediment bed layers= 0
•                               Number of cross sections in river 1= 2
•                               Total number of cross sections used in simulation= 11
•                               Max number of stream tubes= 1
•                               Max number of points in each cross section= 58
•                               Max number of ineffective area in each cross section= 0
•                               Max number of permanent ineffective area in each cross section= 0
•                               Max number of levee area in each cross section= 0
•                               Max number of blocked area in each cross section= 0
•                               Total number of internal boundary conditions= 0
• **** *
.....
```

### D1.2.2 HEC-RAS Geometry Output File (example1\_HEC\_RAS\_GEOMETRY.g01)

This file is a HEC-RAS format geometry file. It is updated each DTPLT time step defined in record YDT. User may use HEC\_RAS model to check the initial input geometry and the final

geometry. This file is too long to be included in this section. It can be found under directory Example 1 in the GSTAR-1D distribution.

### D1.2.3 Bed Profile File (example1\_OUT\_Profile.DAT)

This file is the bed profile file. The meaning of each variable is explained in the file header.

```

• # output bed profile
• # t = time(hr)
• # i = cross section number
• # idxc = original cross section number
• # xt = cross section location (ft or m)
• # q = discharge (cfs or m^3/s)
• # qlatf = lateral flow discharge (cfs or m^3/s)
• # zb0 = original thalweg elevation (ft or m)
• # zb = current thalweg elevation (ft or m)
• # z = current water surface elevation (ft or m)
• # zba = average bed elevation of the main channel (ft or m)
• # fsl ope = friction slope (-)
• # topw = top width (ft or m)
• # hydrad = hydraulic radius (ft or m)
• # d16 = sediment size d16 at bed layer 1 (mm)
• # d35 = sediment size d35 at bed layer 1 (mm)
• # d50 = sediment size d50 at bed layer 1 (mm)
• # d84 = sediment size d84 at bed layer 1 (mm)
• # tshear(j)= bed shear stress at sub-channel j (lb/ft^2 or N/m^2)
• TITLE="bed profile"
• variables=i , idxc, xt, q, qlatf, zb0, zb, zba, fsl ope, topw, hydrad, d16, d35, d50, d84, tshear01
• ZONE T=" t =      0.0000, river # = 1 , river name =
• # i idxc      xt          q          qlatf        zb0          zb
z       zba        fsl ope      topw        hydrad      d16
d35      d50          d84        tshear( 1 )
•   1     1    5000. 00000  14900. 0000  0. 00000000  1005. 00000  1005. 00000
1014. 92466    1007. 85714  0. 999988419E-03  239. 698659  9. 10280805  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   2 #### 4500. 00000  14900. 0000  0. 00000000  1004. 50000  1004. 50000
1014. 42467    1007. 35714  0. 999986014E-03  239. 698687  9. 10281398  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   3 #### 4000. 00000  14900. 0000  0. 00000000  1004. 00000  1004. 00000
1013. 92468    1006. 85714  0. 999983062E-03  239. 698721  9. 10282126  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   4 #### 3500. 00000  14900. 0000  0. 00000000  1003. 50000  1003. 50000
1013. 42469    1006. 35714  0. 999979437E-03  239. 698763  9. 10283020  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   5 #### 3000. 00000  14900. 0000  0. 00000000  1003. 00000  1003. 00000
1012. 92470    1005. 85714  0. 999974986E-03  239. 698815  9. 10284117  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   6 #### 2500. 00000  14900. 0000  0. 00000000  1002. 50000  1002. 50000
1012. 42472    1005. 35714  0. 999969522E-03  239. 698879  9. 10285465  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   7 #### 2000. 00000  14900. 0000  0. 00000000  1002. 00000  1002. 00000
1011. 92474    1004. 85714  0. 999962812E-03  239. 698957  9. 10287119  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   8 #### 1500. 00000  14900. 0000  0. 00000000  1001. 50000  1001. 50000
1011. 42476    1004. 35714  0. 999954575E-03  239. 699052  9. 10289151  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   9 #### 1000. 00000  14900. 0000  0. 00000000  1001. 00000  1001. 00000
1010. 92479    1003. 85714  0. 999944462E-03  239. 699170  9. 10291645  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   10 #### 500. 00000  14900. 0000  0. 00000000  1000. 50000  1000. 50000
1010. 42483    1003. 35714  0. 999932045E-03  239. 699315  9. 10294707  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
•   11     2    0. 00000000  14900. 0000  0. 00000000  1000. 00000  1000. 00000
1009. 92486    1002. 85714  0. 999919879E-03  239. 699456  9. 10297707  0. 399065856
1. 16960984    2. 35737208  13. 3054437  0. 00000000
• ZONE T=" t = 2400. 0000, river # = 1 , river name =
• # i idxc      xt          q          qlatf        zb0          zb
z       zba        fsl ope      topw        hydrad      d16
d35      d50          d84        tshear( 1 )

```

•	1	1	5000. 00000	14900. 0000	0. 00000000	1005. 00000	1005. 05585
	1014. 97785		1007. 90303	0. 100130744E-02	239. 910396	9. 09438981	0. 376862066
	1. 13709280		2. 30223542	13. 0827887	0. 568476832		
•	2	###	4500. 00000	14900. 0000	0. 00000000	1004. 50000	1004. 55478
	1014. 47733		1007. 40214	0. 100110865E-02	239. 908299	9. 09497923	0. 376712567
	1. 13659482		2. 30131665	13. 0864216	0. 568400809		
•	3	###	4000. 00000	14900. 0000	0. 00000000	1004. 00000	1004. 05382
	1013. 97690		1006. 90136	0. 100092000E-02	239. 906578	9. 09553259	0. 376561322
	1. 13609641		2. 30051484	13. 0948569	0. 568328276		
•	4	###	3500. 00000	14900. 0000	0. 00000000	1003. 50000	1003. 55298
	1013. 47655		1006. 40067	0. 100074317E-02	239. 905208	9. 09604588	0. 376419919
	1. 13563035		2. 29992644	13. 1102697	0. 568259939		
•	5	###	3000. 00000	14900. 0000	0. 00000000	1003. 00000	1003. 05228
	1012. 97628		1005. 90009	0. 100059042E-02	239. 904129	9. 09648699	0. 376298559
	1. 13523126		2. 29957906	13. 1313839	0. 568200752		
•	6	###	2500. 00000	14900. 0000	0. 00000000	1002. 50000	1002. 55170
	1012. 47607		1005. 39962	0. 100046015E-02	239. 903297	9. 09686123	0. 376195772
	1. 13489457		2. 29937810	13. 1544549	0. 568150152		
•	7	###	2000. 00000	14900. 0000	0. 00000000	1002. 00000	1002. 05122
	1011. 97592		1004. 89922	0. 100034158E-02	239. 902697	9. 09719836	0. 376102481
	1. 13458994		2. 29917805	13. 1753222	0. 568103869		
•	8	###	1500. 00000	14900. 0000	0. 00000000	1001. 50000	1001. 55080
	1011. 47583		1004. 39887	0. 100022472E-02	239. 902332	9. 09752548	0. 376010466
	1. 13428968		2. 29887298	13. 1912394	0. 568057932		
•	9	###	1000. 00000	14900. 0000	0. 00000000	1001. 00000	1001. 05043
	1010. 97580		1003. 89857	0. 100010614E-02	239. 902210	9. 09785187	0. 375917013
	1. 13398460		2. 29843552	13. 2014508	0. 568010960		
•	10	###	500. 00000	14900. 0000	0. 00000000	1000. 50000	1000. 55012
	1010. 47583		1003. 39832	0. 999987988E-03	239. 902328	9. 09817166	0. 375824048
	1. 13368119		2. 29789854	13. 2066787	0. 567963820		
•	11	2	0. 00000000	14900. 0000	0. 00000000	1000. 00000	1000. 05001
	1009. 97585		1002. 89823	0. 999942844E-03	239. 902417	9. 09829285	0. 375774727
	1. 13353161		2. 29761090	13. 2078576	0. 567945745		

#### D1.2.4 Cross Section Geometry File (example1\_OUT\_XC.DAT)

Due to space limitation, only part of the file is printed here. Interested users may find the complete file under directory Example1.

```

• # output cross section geometry
• # due to disk space limitation, maximum times of geometry printed is 30
• # xc = cross section number
• # t = time(hr)
• # crosloc = transversal coordinate y of bed geometry (ft or m)
• # bottom = vertical coordinate z of bed geometry (ft or m)
• TITLE="cross section geometry"
• VARI ABLES=y, z
• ZONE T=" t =      0. 0000, river # = 1 , river name =
1" , xc =
• # crosloc      bottom
• 0. 00000000 1025. 00000
• 10. 0000000 1020. 00000
• 20. 0000000 1015. 00000
• 30. 0000000 1010. 00000
• 40. 0000000 1005. 00000
• 50. 0000000 1005. 00000
• 60. 0000000 1005. 00000
• 70. 0000000 1005. 00000
• 80. 0000000 1005. 00000
• 90. 0000000 1005. 00000
• 100. 0000000 1005. 00000
• 110. 0000000 1005. 00000
• 120. 0000000 1005. 00000
• 130. 0000000 1005. 00000
• 140. 0000000 1005. 00000
• 150. 0000000 1005. 00000
• 160. 0000000 1005. 00000
• 170. 0000000 1005. 00000
• 180. 0000000 1005. 00000

```

- 190. 000000 1005. 00000
- 200. 000000 1005. 00000
- 210. 000000 1005. 00000
- 220. 000000 1005. 00000
- 230. 000000 1005. 00000
- 240. 000000 1005. 00000
- 250. 000000 1010. 00000
- 260. 000000 1015. 00000
- 270. 000000 1020. 00000
- 280. 000000 1025. 00000
- ZONE T=" t = 0. 0000, river # = 1 , river name = , XC = 2"
- # crossloc bottom
- 0. 00000000 1024. 50000
- 0. 00000000 1024. 50000
- 10. 00000000 1019. 50000
- 20. 00000000 1014. 50000
- 30. 00000000 1009. 50000
- 40. 00000000 1004. 50000
- 50. 00000000 1004. 50000
- 60. 00000000 1004. 50000
- 70. 00000000 1004. 50000
- 80. 00000000 1004. 50000
- 90. 00000000 1004. 50000
- 100. 00000000 1004. 50000
- 110. 00000000 1004. 50000
- 120. 00000000 1004. 50000
- 130. 00000000 1004. 50000
- 140. 00000000 1004. 50000
- 150. 00000000 1004. 50000
- 160. 00000000 1004. 50000
- 170. 00000000 1004. 50000
- 180. 00000000 1004. 50000
- 190. 00000000 1004. 50000
- 200. 00000000 1004. 50000
- 210. 00000000 1004. 50000
- 220. 00000000 1004. 50000
- 230. 00000000 1004. 50000
- 240. 00000000 1004. 50000
- 250. 00000000 1009. 50000
- 260. 00000000 1014. 50000
- 270. 00000000 1019. 50000
- 280. 00000000 1024. 50000
- 280. 00000000 1024. 50000
- .....

### D1.2.5 Cumulative Volume of Deposition File (example1\_OUT\_Volume.DAT)

- # cumulative volume of deposition in each sub-channel
- # i = cross section number
- # xt = cross section location (ft or m)
- # ssumdM = cumulative material volume of deposition in main channel (ft^3 or m^3)
- # ssumdF = cumulative material volume of deposition in floodplain (ft^3 or m^3)
- # ssumdT = cumulative material volume of deposition for entire cross section (ft^3 or m^3)
- # ssumdVM = cumulative bulk volume of deposition in main channel (ft^3 or m^3)
- # ssumdVF = cumulative bulk volume of deposition in floodplain (ft^3 or m^3)
- # ssumdVT = cumulative bulk volume of deposition for entire cross section (ft^3 or m^3)
- # ssumdCT = cumulative bulk volume of consolidation for entire cross section (ft^3 or m^3)
- # t=time(hr)
- TITLE="deposition volume"
- VARIABLES=xt,ssumdM,ssumdF,ssumdT,ssumdVM,ssumdVF,ssumdVT,ssumdCT
- ZONE T=" t = 0. 0000, river # = 1 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF
- ssumdVT ssumdCT
- 1 0. 5000E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00

- 2 0.4500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 3 0.4000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 4 0.3500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 5 0.3000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 6 0.2500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 7 0.2000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5000E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 2400.0000, river # = 1 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF
- ssumdVT ssumdCT
- 1 0.5000E+04 0.1927E+04 0.0000E+00 0.1927E+04 0.3212E+04 0.0000E+00
- 0.3212E+04 0.2125E-07
- 2 0.4500E+04 0.3780E+04 0.0000E+00 0.3780E+04 0.6300E+04 0.0000E+00
- 0.6300E+04 0.4234E-07
- 3 0.4000E+04 0.3714E+04 0.0000E+00 0.3714E+04 0.6190E+04 0.0000E+00
- 0.6190E+04 0.4394E-07
- 4 0.3500E+04 0.3656E+04 0.0000E+00 0.3656E+04 0.6093E+04 0.0000E+00
- 0.6093E+04 0.4154E-07
- 5 0.3000E+04 0.3608E+04 0.0000E+00 0.3608E+04 0.6013E+04 0.0000E+00
- 0.6013E+04 0.4176E-07
- 6 0.2500E+04 0.3568E+04 0.0000E+00 0.3568E+04 0.5947E+04 0.0000E+00
- 0.5947E+04 0.4495E-07
- 7 0.2000E+04 0.3535E+04 0.0000E+00 0.3535E+04 0.5891E+04 0.0000E+00
- 0.5891E+04 0.4085E-07
- 8 0.1500E+04 0.3505E+04 0.0000E+00 0.3505E+04 0.5842E+04 0.0000E+00
- 0.5842E+04 0.3600E-07
- 9 0.1000E+04 0.3480E+04 0.0000E+00 0.3480E+04 0.5800E+04 0.0000E+00
- 0.5800E+04 0.3803E-07
- 10 0.5000E+03 0.3459E+04 0.0000E+00 0.3459E+04 0.5764E+04 0.0000E+00
- 0.5764E+04 0.4101E-07
- 11 0.0000E+00 0.1726E+04 0.0000E+00 0.1726E+04 0.2876E+04 0.0000E+00
- 0.2876E+04 0.2072E-07

### D1.2.6 Material Volume of Deposition in Each Sub-Channel (example1\_OUT\_MaterialVolume.DAT)

- # material volume of deposition in each size fraction
- # i =cross section number
- # xt=cross section location (ft or m)
- # ssd\_mat(0) = material volume of deposition in all size fractions (ft^3 or m^3)
- # ssd\_mat(m) = material volume of deposition in m size fraction (ft^3 or m^3)
- # t=time(hr)
- TITLE="deposition material volume"
- VARIABLES=
- i,xt,ssd\_mat00,ssd\_mat01,ssd\_mat02,ssd\_mat03,ssd\_mat04,ssd\_mat05,ssd\_mat06,ssd\_mat07,ssd\_mat08,ssd\_mat09,ssd\_mat10,ssd\_mat11
- ZONE T=" t = 0.0000, river # = 1 , river name = "
- # i xt ssd\_mat(00) ssd\_mat(01) ssd\_mat(02) ssd\_mat(03) ssd\_mat(04)
- ssd\_mat(05) ssd\_mat(06) ssd\_mat(07) ssd\_mat(08) ssd\_mat(09) ssd\_mat(10) ssd\_mat(11)
- 1 0.5000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 2 0.4500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 3 0.4000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 4 0.3500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

- 5 0.3000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 6 0.2500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 7 0.2000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5000E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 2400.000, river # = 1 , river name = "
- # i xt ssd\_mat(00) ssd\_mat(01) ssd\_mat(02) ssd\_mat(03) ssd\_mat(04)
- ssd\_mat(05) ssd\_mat(06) ssd\_mat(07) ssd\_mat(08) ssd\_mat(09) ssd\_mat(10) ssd\_mat(11)
- 1 0.5000E+04 0.1927E+04 0.0000E+00 0.1036E+04 0.1066E+03 0.1795E+03
- 0.2002E+03 0.2703E+03 0.7073E+02 0.8491E+02 0.1409E+03 -0.1624E+03 0.0000E+00
- 2 0.4500E+04 0.3780E+04 0.0000E+00 0.2071E+04 0.2122E+03 0.3565E+03
- 0.3969E+03 0.4976E+03 0.1254E+03 0.1617E+03 0.2778E+03 -0.3193E+03 0.0000E+00
- 3 0.4000E+04 0.3714E+04 0.0000E+00 0.2072E+04 0.2118E+03 0.3549E+03
- 0.3941E+03 0.4437E+03 0.1098E+03 0.1541E+03 0.2743E+03 -0.3007E+03 0.0000E+00
- 4 0.3500E+04 0.3656E+04 0.0000E+00 0.2073E+04 0.2118E+03 0.3539E+03
- 0.3921E+03 0.3756E+03 0.9391E+02 0.1466E+03 0.2711E+03 -0.2620E+03 0.0000E+00
- 5 0.3000E+04 0.3608E+04 0.0000E+00 0.2074E+04 0.2119E+03 0.3532E+03
- 0.3906E+03 0.2999E+03 0.7747E+02 0.1389E+03 0.2676E+03 -0.2059E+03 0.0000E+00
- 6 0.2500E+04 0.3568E+04 0.0000E+00 0.2075E+04 0.2121E+03 0.3527E+03
- 0.3894E+03 0.2259E+03 0.6096E+02 0.1308E+03 0.2639E+03 -0.1429E+03 0.0000E+00
- 7 0.2000E+04 0.3535E+04 0.0000E+00 0.2076E+04 0.2124E+03 0.3526E+03
- 0.3887E+03 0.1613E+03 0.4541E+02 0.1225E+03 0.2599E+03 -0.8476E+02 0.0000E+00
- 8 0.1500E+04 0.3505E+04 0.0000E+00 0.2078E+04 0.2130E+03 0.3529E+03
- 0.3885E+03 0.1103E+03 0.3200E+02 0.1141E+03 0.2560E+03 -0.3961E+02 0.0000E+00
- 9 0.1000E+04 0.3480E+04 0.0000E+00 0.2080E+04 0.2140E+03 0.3539E+03
- 0.3890E+03 0.7310E+02 0.2156E+02 0.1054E+03 0.2521E+03 -0.9510E+01 0.0000E+00
- 10 0.5000E+03 0.3459E+04 0.0000E+00 0.2083E+04 0.2154E+03 0.3553E+03
- 0.3900E+03 0.4805E+02 0.1447E+02 0.9655E+02 0.2481E+03 0.7817E+01 0.0000E+00
- 11 0.0000E+00 0.1726E+04 0.0000E+00 0.1043E+04 0.1081E+03 0.1781E+03
- 0.1953E+03 0.2005E+02 0.5918E+01 0.4602E+02 0.1229E+03 0.6629E+01 0.0000E+00

### D1.2.7 Mass Balance File (example1\_OUT\_MassBalance.DAT)

- # mass balance
- # this mass balance check is only valid for sslove = 1, when neglecting
- # suspended sediment change
- # t=time(hr)
- # massbal = balance of material volume (ft^3 or m^3)
- # sumtin = material volume of sediment entering upstream boundary (ft^3 or m^3)
- # sumtex = material volume of erosion exiting downstream boundary (ft^3 or m^3)
- # sumtlt = material volume of sediment entering laterally (ft^3 or m^3)
- # sume = material volume of erosion (ft^3 or m^3)
- TITLE="mass balance"
- VARIABLES=
  - t, massbal00, sumtin00, masstex00, masstl t00, sume00, massbal01, sumtin01, masstex01, masstl t01, sume01, massbal02, sumtin02, masstex02, masstl t02, sume02, massbal03, sumtin03, masstex03, masstl t03, sume03, massbal04, sumtin04, masstex04, masstl t04, sume04, massbal05, sumtin05, masstex05, masstl t05, sume05, massbal06, sumtin06, masstex06, masstl t06, sume06, massbal07, sumtin07, masstex07, masstl t07, sume07, massbal08, sumtin08, masstex08, masstl t08, sume08, massbal09, sumtin09, masstex09, masstl t09, sume09, massbal10, sumtin10, masstex10, masstl t10, sume10, massbal11, sumtin11, masstex11, masstl t11, sume11
- ZONE T=" mass balance"
- # | size 0 | size 2 |
- size 1 | size 3 | size 4 |
- size 5 | size 6 |
- size 7 | size 8 |
- size 9 | size 10 |
- size 11 | |
- # tt massbal sumtin sumtex sumtlt sume massbal sumtex sumtlt
- sumtin sumtex sumtin sume sumbal sumtlt sume sumbal sumtex sumtin sume
- sumtex sumtlt sume massbal sumtin sume sumbal sumtlt sumtin sume

massbal	sumtin	sumtex	sumlt	sume	massbal	sumtin	sumtex	massbal	
sumlt	sume	massbal	sumtin	sumtex	sumlt	sume	sumtex	sumlt	
sumtin	sumtex	sumlt	sume	massbal	sumtin	sume	sumtex	sumlt	
sume	massbal	sumtin	sumtex	sumlt	sume	massbal	sumtex	sumlt	
• 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
• 0.2400E+04 -0.3069E-05 0.5861E+08 0.5857E+08 0.0000E+00 -0.3596E+05 0.0000E+00	0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 -0.3328E-05 0.3233E+08 0.3231E+08	0.0000E+00 -0.2076E+05 -0.1679E-06 0.7292E+07 0.7290E+07 0.0000E+00 -0.2129E+04 0.6311E-06	0.8493E+07 0.8490E+07 0.0000E+00 -0.3543E+04 -0.2644E-06 0.9185E+07 0.9181E+07	0.0000E+00 -0.3915E+04 0.1435E-07 0.1993E+06 0.1968E+06 0.0000E+00 -0.2526E+04 -0.3872E-08	0.3165E+06 0.3159E+06 0.0000E+00 -0.6576E+03 0.2984E-07 0.3751E+06 0.3738E+06 0.0000E+00	-0.1302E+04 0.2150E-07 0.3869E+06 0.3842E+06 0.0000E+00 -0.2634E+04 -0.1995E-08	0.3517E+05 0.3668E+05 0.0000E+00 0.1513E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00	0.0000E+00 0.0000E+00	

### D1.2.8 Sediment Load File (example1\_OUT\_SedimentLoad.DAT)

```

• # cumulative sediment load passing cross section in each sub-channel
• # i = cross section number
• # xt = cross section location (ft or m)
• # ssed(j, 0) = cumulative sediment load passing in sub-channel j (tons or metric tons)
• # ssed(j, m) = cumulative sediment load passing for size fraction m in sub-channel j (tons or metric tons)
• # t = time(hr)
• TITLE = "sediment load"
• VARIABLES=
i, xt, ssed(01_00), ssed(01_01), ssed(01_02), ssed(01_03), ssed(01_04), ssed(01_05), ssed(01_06), ssed(01_07), ssed(01_08), ssed(01_09), ssed(01_10), ssed(01_11)
• ZONE T="t" = 0.0000, river # = 1, river name =
""
• # i xt ssed(01, 00) ssed(01, 01) ssed(01, 02) ssed(01, 03) ssed(01, 04)
ssed(01, 05) ssed(01, 06) ssed(01, 07) ssed(01, 08) ssed(01, 09) ssed(01, 10) ssed(01, 11)
• 1 0.500000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 2 0.450000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 3 0.400000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 4 0.350000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 5 0.300000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 6 0.250000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 7 0.200000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 8 0.150000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 9 0.100000E+04 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 10 0.500000E+03 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00
• 11 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00

```

- VARI ABLES=
  - i , xt , ssed(01\_00) , ssed(01\_01) , ssed(01\_02) , ssed(01\_03) , ssed(01\_04) , ssed(01\_05) , ssed(01\_06) , ssed(01\_07) , ssed(01\_08) , ssed(01\_09) , ssed(01\_10) , ssed(01\_11)
- ZONE T=" t = 2400.0000, river # = 1 , river name = "
- # i xt ssed(01\_00) ssed(01\_01) ssed(01\_02) ssed(01\_03) ssed(01\_04) ssed(01\_05) ssed(01\_06) ssed(01\_07) ssed(01\_08) ssed(01\_09) ssed(01\_10) ssed(01\_11)
- 1 0. 500000E+04 0. 484782E+07 0. 000000E+00 0. 267384E+07 0. 603140E+06 0. 702528E+06 0. 759738E+06 0. 164624E+05 0. 261759E+05 0. 310231E+05 0. 319882E+05 0. 292251E+04 0. 000000E+00
- 2 0. 450000E+04 0. 484751E+07 0. 000000E+00 0. 267367E+07 0. 603123E+06 0. 702498E+06 0. 759705E+06 0. 164213E+05 0. 261655E+05 0. 310098E+05 0. 319652E+05 0. 294892E+04 0. 000000E+00
- 3 0. 400000E+04 0. 484720E+07 0. 000000E+00 0. 267350E+07 0. 603105E+06 0. 702469E+06 0. 759672E+06 0. 163846E+05 0. 261564E+05 0. 309970E+05 0. 319425E+05 0. 297379E+04 0. 000000E+00
- 4 0. 350000E+04 0. 484690E+07 0. 000000E+00 0. 267333E+07 0. 603088E+06 0. 702439E+06 0. 759640E+06 0. 163535E+05 0. 261486E+05 0. 309849E+05 0. 319201E+05 0. 299546E+04 0. 000000E+00
- 5 0. 300000E+04 0. 484660E+07 0. 000000E+00 0. 267316E+07 0. 603070E+06 0. 702410E+06 0. 759608E+06 0. 163287E+05 0. 261422E+05 0. 309734E+05 0. 318980E+05 0. 301249E+04 0. 000000E+00
- 6 0. 250000E+04 0. 484630E+07 0. 000000E+00 0. 267298E+07 0. 603052E+06 0. 702381E+06 0. 759575E+06 0. 163100E+05 0. 261372E+05 0. 309626E+05 0. 318762E+05 0. 302431E+04 0. 000000E+00
- 7 0. 200000E+04 0. 484601E+07 0. 000000E+00 0. 267281E+07 0. 603035E+06 0. 702352E+06 0. 759543E+06 0. 162966E+05 0. 261334E+05 0. 309524E+05 0. 318547E+05 0. 303132E+04 0. 000000E+00
- 8 0. 150000E+04 0. 484572E+07 0. 000000E+00 0. 267264E+07 0. 603017E+06 0. 702323E+06 0. 759511E+06 0. 162875E+05 0. 261308E+05 0. 309430E+05 0. 318335E+05 0. 303460E+04 0. 000000E+00
- 9 0. 100000E+04 0. 484543E+07 0. 000000E+00 0. 267247E+07 0. 603000E+06 0. 702293E+06 0. 759479E+06 0. 162815E+05 0. 261290E+05 0. 309343E+05 0. 318126E+05 0. 303538E+04 0. 000000E+00
- 10 0. 500000E+03 0. 484515E+07 0. 000000E+00 0. 267230E+07 0. 602982E+06 0. 702264E+06 0. 759447E+06 0. 162775E+05 0. 261278E+05 0. 309263E+05 0. 317921E+05 0. 303474E+04 0. 000000E+00
- 11 0. 000000E+00 0. 484501E+07 0. 000000E+00 0. 267221E+07 0. 602973E+06 0. 702249E+06 0. 759430E+06 0. 162758E+05 0. 261273E+05 0. 309225E+05 0. 317820E+05 0. 303419E+04 0. 000000E+00

### D1.2.9 Sediment Concentration File (example1\_OUT\_Conc.DAT)

- # concentration in each sub-channel
- # i = cross section number
- # xt = cross section location (ft or m)
- # conc(j, 0) = total concentration in sub-channel j (mg/l)
- # conc(j, m) = concentration of size m in sub-channel j (mg/l)
- # t = time(hr)
- TITLE = "concentration"
- VARI ABLES=
  - i , xt , conc(01\_00) , conc(01\_01) , conc(01\_02) , conc(01\_03) , conc(01\_04) , conc(01\_05) , conc(01\_06) , conc(01\_07) , conc(01\_08) , conc(01\_09) , conc(01\_10) , conc(01\_11)
- ZONE T=" t = 0.0000, river # = 1 , river name = "
- # i xt conc(01\_00) conc(01\_01) conc(01\_02) conc(01\_03) conc(01\_04) conc(01\_05) conc(01\_06) conc(01\_07) conc(01\_08) conc(01\_09) conc(01\_10) conc(01\_11)
- 1 0. 5000E+04 0. 0000E+00 0. 0000E+00
- 2 0. 4500E+04 0. 0000E+00 0. 0000E+00
- 3 0. 4000E+04 0. 0000E+00 0. 0000E+00
- 4 0. 3500E+04 0. 0000E+00 0. 0000E+00
- 5 0. 3000E+04 0. 0000E+00 0. 0000E+00
- 6 0. 2500E+04 0. 0000E+00 0. 0000E+00
- 7 0. 2000E+04 0. 0000E+00 0. 0000E+00
- 8 0. 1500E+04 0. 0000E+00 0. 0000E+00

- 9 0.1000E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5000E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- VARI ABLES=
- i , xt , conc(01\_00) , conc(01\_01) , conc(01\_02) , conc(01\_03) , conc(01\_04) , conc(01\_05) , conc(01\_06) , conc(01\_07) , conc(01\_08) , conc(01\_09) , conc(01\_10) , conc(01\_11)
- ZONE T=" t = 2400.0000 , river # = 1 , river name = "
- # i xt conc(01,00) conc(01,01) conc(01,02) conc(01,03) conc(01,04) conc(01,05) conc(01,06) conc(01,07) conc(01,08) conc(01,09) conc(01,10) conc(01,11)
- 1 0.5000E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1892E+03 0.4103E+01 0.6517E+01 0.7724E+01 0.7966E+01 0.7239E+00 0.0000E+00
- 2 0.4500E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4099E+01 0.6514E+01 0.7722E+01 0.7964E+01 0.7236E+00 0.0000E+00
- 3 0.4000E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4093E+01 0.6511E+01 0.7720E+01 0.7963E+01 0.7248E+00 0.0000E+00
- 4 0.3500E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4086E+01 0.6508E+01 0.7718E+01 0.7961E+01 0.7281E+00 0.0000E+00
- 5 0.3000E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4078E+01 0.6505E+01 0.7716E+01 0.7959E+01 0.7333E+00 0.0000E+00
- 6 0.2500E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4069E+01 0.6502E+01 0.7713E+01 0.7957E+01 0.7393E+00 0.0000E+00
- 7 0.2000E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1502E+03 0.1749E+03 0.1891E+03 0.4062E+01 0.6499E+01 0.7710E+01 0.7955E+01 0.7449E+00 0.0000E+00
- 8 0.1500E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1501E+03 0.1749E+03 0.1891E+03 0.4055E+01 0.6496E+01 0.7708E+01 0.7953E+01 0.7490E+00 0.0000E+00
- 9 0.1000E+04 0.1207E+04 0.0000E+00 0.6657E+03 0.1501E+03 0.1749E+03 0.1891E+03 0.4051E+01 0.6493E+01 0.7705E+01 0.7951E+01 0.7516E+00 0.0000E+00
- 10 0.5000E+03 0.1207E+04 0.0000E+00 0.6657E+03 0.1501E+03 0.1749E+03 0.1891E+03 0.4047E+01 0.6491E+01 0.7701E+01 0.7948E+01 0.7528E+00 0.0000E+00
- 11 0.0000E+00 0.1207E+04 0.0000E+00 0.6657E+03 0.1501E+03 0.1749E+03 0.1891E+03 0.4046E+01 0.6491E+01 0.7700E+01 0.7947E+01 0.7532E+00 0.0000E+00

### D1.2.10 Bed Fraction File (example1\_OUT\_BedFraction.DAT)

- # bed material fraction in each sub-channel
- # i = cross section number
- # xt = cross section location (ft or m)
- # pn(n, m) = bed material fraction of size m in layer n (1/1)
- # t=time(hr)
- TITLE="bed fraction"
- VARI ABLES=
- i , xt , pn(01\_01) , pn(01\_02) , pn(01\_03) , pn(01\_04) , pn(01\_05) , pn(01\_06) , pn(01\_07) , pn(01\_08) , pn(01\_09) , pn(01\_10) , pn(01\_11)
- ZONE T=" t = 0.0000 , river # = 1 , river name = , sub-channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5) pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0.5000E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 2 0.4500E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 3 0.4000E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 4 0.3500E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 5 0.3000E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 6 0.2500E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 7 0.2000E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 8 0.1500E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 9 0.1000E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 10 0.5000E+03 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00 0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01

- 11 0.0000E+00 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- ZONE T=" t = 2400.0000, river # = 1 , river name = , sub-channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0.5000E+04 0.0000E+00 0.1111E+00 0.8255E-01 0.1294E+00 0.1453E+00  
0.1557E+00 0.1393E+00 0.1079E+00 0.8579E-01 0.3008E-01 0.1279E-01
- 2 0.4500E+04 0.0000E+00 0.1112E+00 0.8257E-01 0.1294E+00 0.1453E+00  
0.1556E+00 0.1393E+00 0.1079E+00 0.8580E-01 0.3011E-01 0.1279E-01
- 3 0.4000E+04 0.0000E+00 0.1112E+00 0.8259E-01 0.1295E+00 0.1454E+00  
0.1554E+00 0.1392E+00 0.1079E+00 0.8581E-01 0.3020E-01 0.1279E-01
- 4 0.3500E+04 0.0000E+00 0.1112E+00 0.8261E-01 0.1295E+00 0.1454E+00  
0.1552E+00 0.1392E+00 0.1079E+00 0.8582E-01 0.3037E-01 0.1280E-01
- 5 0.3000E+04 0.0000E+00 0.1113E+00 0.8263E-01 0.1295E+00 0.1454E+00  
0.1549E+00 0.1392E+00 0.1079E+00 0.8582E-01 0.3062E-01 0.1280E-01
- 6 0.2500E+04 0.0000E+00 0.1113E+00 0.8264E-01 0.1295E+00 0.1454E+00  
0.1546E+00 0.1391E+00 0.1079E+00 0.8582E-01 0.3089E-01 0.1280E-01
- 7 0.2000E+04 0.0000E+00 0.1113E+00 0.8266E-01 0.1295E+00 0.1455E+00  
0.1543E+00 0.1391E+00 0.1079E+00 0.8582E-01 0.3115E-01 0.1280E-01
- 8 0.1500E+04 0.0000E+00 0.1113E+00 0.8267E-01 0.1296E+00 0.1455E+00  
0.1541E+00 0.1390E+00 0.1079E+00 0.8581E-01 0.3135E-01 0.1280E-01
- 9 0.1000E+04 0.0000E+00 0.1113E+00 0.8268E-01 0.1296E+00 0.1455E+00  
0.1540E+00 0.1390E+00 0.1078E+00 0.8580E-01 0.3148E-01 0.1281E-01
- 10 0.5000E+03 0.0000E+00 0.1114E+00 0.8270E-01 0.1296E+00 0.1455E+00  
0.1539E+00 0.1390E+00 0.1078E+00 0.8579E-01 0.3156E-01 0.1281E-01
- 11 0.0000E+00 0.0000E+00 0.1114E+00 0.8270E-01 0.1296E+00 0.1455E+00  
0.1539E+00 0.1390E+00 0.1078E+00 0.8579E-01 0.3158E-01 0.1281E-01

### D1.2.11 Sediment Porosity File (example1\_OUT\_Porosity.DAT)

- # maximum porosity in each sub-channel and layer of bed
- # i =cross section number
- # xt=cross section location (ft or m)
- # porsty(n,0) = porosity in bed layer n (-)
- # porsty(n,m) = relative porosity in bed of size m in layer n (-)
- # t=time(hr)
- TITLE="porosity"
- VARIABLES=  
i, xt, porsty01\_00, porsty01\_01, porsty01\_02, porsty01\_03, porsty01\_04, porsty01\_05, porsty01\_06, porsty01\_07, porsty01\_08, porsty01\_09, porsty01\_10, porsty01\_11
- ZONE T=" t = 0.0000, river # = 1 , river name = , sub-channel = 1"
- # i xt porsty( 1, 0) porsty( 1, 1) porsty( 1, 2) porsty( 1, 3) porsty( 1, 4)  
porsty( 1, 5) porsty( 1, 6) porsty( 1, 7) porsty( 1, 8) porsty( 1, 9) porsty( 1, 10) porsty( 1, 11)
- 1 0.5000E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 2 0.4500E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 3 0.4000E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 4 0.3500E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 5 0.3000E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 6 0.2500E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 7 0.2000E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 8 0.1500E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 9 0.1000E+04 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 10 0.5000E+03 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- 11 0.0000E+00 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01  
0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01 0.1000E+01
- ZONE T=" t = 2400.0000, river # = 1 , river name = , sub-channel = 1"

- # i xt porsty( 1, 0) porsty( 1, 1) porsty( 1, 2) porsty( 1, 3) porsty( 1, 4)  
 porsty( 1, 5) porsty( 1, 6) porsty( 1, 7) porsty( 1, 8) porsty( 1, 9) porsty( 1, 10) porsty( 1, 11)
- 1 0.5000E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 2 0.4500E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 3 0.4000E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 4 0.3500E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 5 0.3000E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 6 0.2500E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 7 0.2000E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 8 0.1500E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 9 0.1000E+04 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 10 0.5000E+03 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 11 0.0000E+00 0.4000E+00 0.3869E+00 0.4000E+00 0.4000E+00 0.4000E+00
- 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00 0.4000E+00

### D1.3 Final Remarks

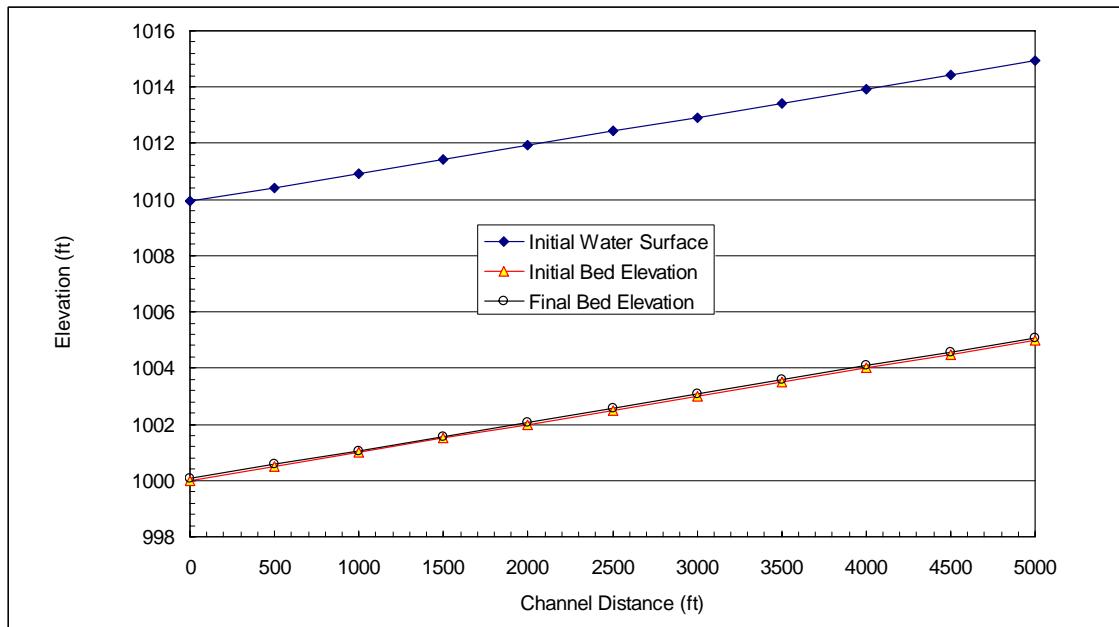


Figure D1.2 Bed elevation and water surface

Figure D1.2 shows the initial and final bed elevation and water surface elevation profiles. The incoming sediment load near equilibrium condition, the bed elevation change is small. The user may change the incoming sediment load to see the result of erosion and deposition.

## EXAMPLE 2 CHANNEL NETWORK

This example shows a GSTAR-1D input data file set-up for a simple network channel with sediment transport. The network is composed of 4 trapezoid channels as shown in Figure D2.1. Rivers are numbered in ascending order from upstream to downstream. Each channel is 1 mile (5,280 ft) long with a trapezoid cross section of bottom width of 200 ft and side slopes of 1V:2H. The upstream water discharge is 14,900 cfs and the downstream water surface elevation is set to a fixed depth. Each channel was input with two original cross sections and 9 interpolated cross sections.

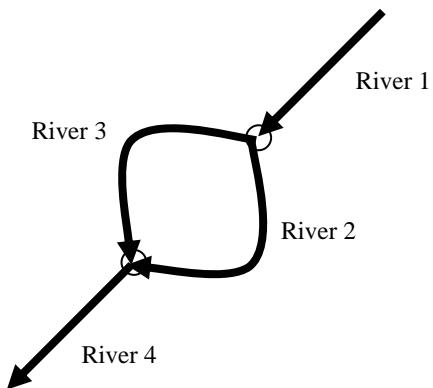


Figure D2.1 Sketch showing the river network

The downstream boundary of river 1 is defined in Record D00 (D00 -2, -3). This record shows river 1 is connected with rivers 2 and 3 at downstream. Negative numbers represent that flow directions in river 2 and river 3 are out of the junction. The upstream boundary of river 2 is defined in Record U00 (U00 1, -3). The record shows river 2 is connected with rivers 1 and 3 at its upstream end. A positive number 1 represents that the flow direction in river 1 is into the junction. Negative number -3 represents that the flow direction in river 3 is out of the junction. The boundary conditions of junction are defined in the same way for rivers 3 and 4.

The input sediment load is 57709 ton/day and 11 sediment sizes are used ranging from silt to small cobble. The incoming sediment size distribution is given in record USS. Two bed layers (one active layer and one inactive layer) are used. The active layer thickness is calculated from the input value of NALT in record SAT. Bed size distributions are set using BLP records.

## D2.1 Input Data File (example2.dat)

The files shown in this and the next sections are part of the main GSTAR-1D distribution package. They can be found under directory Example2.

```

YTT GSTAR-1D version 1.1 Example data file for Appendix D of user's manual .
YTT Network of 4 trapezoidal channels with sediment transport.
YTT ****
*** NOTE: this is a datafile to be used as an example of input data as it ***
*** might be used in a GSTARS-1D version 1.0 simulation. It represents a ***
*** fictitious case and it should be viewed as such. It should not be used ***
*** for any other purpose without appropriate verification and validation.
*** -----
*** Problem Description: Network of 4 trapezoidal channels
*** with sediment transport
*** Rivers 2 and 3 are connected upstream and downstream
*** River 1 are connected with rivers 2 and 3 at upstream
*** River 4 are connected with rivers 2 and 3 at downstream
*** Data filename: network.data
*** Shape: trapezoidal channel, top width = 200 + 4y ft (61 + 4y m).
*** Side Slopes: 1V:2H
*** Channel Length: 5280 ft (1609 m) each.
*** Channel Slope (s): 0.00095
*** Number of Stations: 11 each channel equally spaced at 528 ft (161 m).
*** -----
*** ****
***      nriv      nf      nl ay
YNR        4       11       2
***      i solve i solves      EPSY      F1      XFACT      METRIC      YZ
YSL        1       1 1.0E-04      1      5280       0       0
***      KFLP      qmin
YFP        0       0
***      THE      i HotSt
YTM      2400       0
***      TDT      DT      DTPLT      xcplt      xcplt
YDT        0       1     2400       5       27
***      Start of River      1
***      KU(J)
UFB        2
***      T1      ST1
U02        0     14900
U02        2     14900
U02        3     14900
U02      2400     14900
***      KD(J)
DFB        0
***      DRI V(I , J)      (+) if entering, (-) if exiting
D00      -2      -3
***      NKI (J) b.c. for internal station
INF        0
***      NKQF(J) non-point flow source
LNF        0
***      FLDST      ZDI      QDI -----cross section      1
XIN        0       0       0
***      xt      bec      ni nterp      i HotC
XST      1.000      15      9       0
***      station elevation data
XSP      1020       0     1015      10     1010      20     1005      30     1000      40
XSP      1000      50     1000      60     1000      70     1000      80     1000      90
XSP      1000      100     1000     110     1000     120     1000     130     1000     140
XSP      1000      150     1000     160     1000     170     1000     180     1000     190
XSP      1000      200     1000     210     1000     220     1000     230     1000     240
XSP      1005      250     1010     260     1015     270     1020     280
***      xl oc_rcoef rcoef
XRH        40      0.03     240      0.03     280      0.03
***      bankl bankr
XOX        0      280
***      KEXP KCON
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      5280       0     5280     280
***      FLDST      ZDI      QDI -----cross section      2
XIN        0       0       0

```

```

***      xt     bec    ni   nterp   i HotC
XST      0.00      10      0      0
***      station elevation data
XSP      1020       0     1015      10    1010      20    1005      30    1000      40
XSP      1000       50    1000      60    1000      70    1000      80    1000      90
XSP      1000      100    1000     110    1000     120    1000     130    1000     140
XSP      1000      150    1000     160    1000     170    1000     180    1000     190
XSP      1000      200    1000     210    1000     220    1000     230    1000     240
XSP      1005      250    1010     260    1015     270    1020     280
***      xl oc_rcoef rcoef
XRH      40      0.03      240      0.03      280      0.03
***      bankl bankr
XOX      0      280
***      KEXP KCON
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      0      0      0      280
***      End of River      1
***      Start of River      2
***      KU(J)
UFB      0
***      URI V(I,J)      (+) if entering, (-) if exiting
UOO      1      -3
***      KD(J)
DFB      0
***      DRI V(I,J)      (+) if entering, (-) if exiting
D00      3      -4
***      NKI (J) b.c. for internal station
INF      0
***      NKQF(J) non-point flow source
LNF      0
***      FLDST      ZDI      QDI -----cross section      1
XIN      0      0      0
***      station elevation data
XST      1.000      10      9      0
***      station elevation data
XSP      1020       0     1015      10    1010      20    1005      30    1000      40
XSP      1000       50    1000      60    1000      70    1000      80    1000      90
XSP      1000      100    1000     110    1000     120    1000     130    1000     140
XSP      1000      150    1000     160    1000     170    1000     180    1000     190
XSP      1000      200    1000     210    1000     220    1000     230    1000     240
XSP      1005      250    1010     260    1015     270    1020     280
***      xl oc_rcoef rcoef
XRH      40      0.03      240      0.03      280      0.03
***      bankl bankr
XOX      0      280
***      KEXP KCON
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      5280      0      5280      280
***      FLDST      ZDI      QDI -----cross section      2
XIN      0      0      0
***      station elevation data
XST      0.000      5      0      0
***      station elevation data
XSP      1020       0     1015      10    1010      20    1005      30    1000      40
XSP      1000       50    1000      60    1000      70    1000      80    1000      90
XSP      1000      100    1000     110    1000     120    1000     130    1000     140
XSP      1000      150    1000     160    1000     170    1000     180    1000     190
XSP      1000      200    1000     210    1000     220    1000     230    1000     240
XSP      1005      250    1010     260    1015     270    1020     280
***      xl oc_rcoef rcoef
XRH      40      0.03      240      0.03      280      0.03
***      bankl bankr
XOX      0      280
***      KEXP KCON
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      0      0      0      280
***      End of River      2
***      Start of River      3
***      KU(J)
UFB      0
***      URI V(I,J)      (+) if entering, (-) if exiting
UOO      1      -2
***      KD(J)
DFB      0
***      DRI V(I,J)      (+) if entering, (-) if exiting
D00      2      -4
***      NKI (J) b.c. for internal station

```

INF 0  
 \*\*\* NKQF(J) non-point flow source  
 LNF 0  
 \*\*\* FLDST ZDI QDI -----cross section 1  
 XIN 0 0 0  
 \*\*\* xt bec ni nterp i HotC  
 XST 1.0 10 9 0  
 \*\*\* station elevation data  
 XSP 1020 0 1015 10 1010 20 1005 30 1000 40  
 XSP 1000 50 1000 60 1000 70 1000 80 1000 90  
 XSP 1000 100 1000 110 1000 120 1000 130 1000 140  
 XSP 1000 150 1000 160 1000 170 1000 180 1000 190  
 XSP 1000 200 1000 210 1000 220 1000 230 1000 240  
 XSP 1005 250 1010 260 1015 270 1020 280  
 \*\*\* xl oc\_rcoef rcoef  
 XRH 40 0.03 240 0.03 280 0.03  
 \*\*\* bankl bankr  
 XOX 0 280  
 \*\*\* KEXP KCON  
 XFL 0.3 0.1  
 \*\*\* xl yl xr yr  
 XSL 5280 0 5280 280  
 \*\*\* FLDST ZDI QDI -----cross section 2  
 XIN 0 0 0  
 \*\*\* xt bec ni nterp i HotC  
 XST 0.00 5 0 0  
 \*\*\* station elevation data  
 XSP 1020 0 1015 10 1010 20 1005 30 1000 40  
 XSP 1000 50 1000 60 1000 70 1000 80 1000 90  
 XSP 1000 100 1000 110 1000 120 1000 130 1000 140  
 XSP 1000 150 1000 160 1000 170 1000 180 1000 190  
 XSP 1000 200 1000 210 1000 220 1000 230 1000 240  
 XSP 1005 250 1010 260 1015 270 1020 280  
 \*\*\* xl oc\_rcoef rcoef  
 XRH 40 0.03 240 0.03 280 0.03  
 \*\*\* bankl bankr  
 XOX 0 280  
 \*\*\* KEXP KCON  
 XFL 0.3 0.1  
 \*\*\* xl yl xr yr  
 XSL 0 0 0 280  
 \*\*\* End of River 3  
 \*\*\* Start of River 4  
 \*\*\* KU(J)  
 UFB 0  
 \*\*\* URI V(I,J) (+) if entering, (-) if exiting  
 UOO 2 3  
 \*\*\* KD(J)  
 DFB 1  
 \*\*\* TN STN  
 D01 2400 1010  
 \*\*\* NKI (J) b.c. for internal station  
 INF 0  
 \*\*\* NKQF(J) non-point flow source  
 LNF 0  
 \*\*\* FLDST ZDI QDI -----cross section 1  
 XIN 0 0 0  
 \*\*\* xt bec ni nterp i HotC  
 XST 1.00 5 9 0  
 \*\*\* station elevation data  
 XSP 1020 0 1015 10 1010 20 1005 30 1000 40  
 XSP 1000 50 1000 60 1000 70 1000 80 1000 90  
 XSP 1000 100 1000 110 1000 120 1000 130 1000 140  
 XSP 1000 150 1000 160 1000 170 1000 180 1000 190  
 XSP 1000 200 1000 210 1000 220 1000 230 1000 240  
 XSP 1005 250 1010 260 1015 270 1020 280  
 \*\*\* xl oc\_rcoef rcoef  
 XRH 40 0.03 240 0.03 280 0.03  
 \*\*\* bankl bankr  
 XOX 0 280  
 \*\*\* KEXP KCON  
 XFL 0.3 0.1  
 \*\*\* xl yl xr yr  
 XSL 5280 0 5280 280  
 \*\*\* FLDST ZDI QDI -----cross section 2  
 XIN 0 0 0  
 \*\*\* xt bec ni nterp i HotC  
 XST 0.00 0 0 0  
 \*\*\* station elevation data  
 XSP 1020 0 1015 10 1010 20 1005 30 1000 40  
 XSP 1000 50 1000 60 1000 70 1000 80 1000 90

```

XSP      1000    100    1000    110    1000    120    1000    130    1000    140
XSP      1000    150    1000    160    1000    170    1000    180    1000    190
XSP      1000    200    1000    210    1000    220    1000    230    1000    240
XSP      1005    250    1010    260    1015    270    1020    280
*** xl oc_rcoef rcoef
XRH      40      0.03   240     0.03   280     0.03
*** bankl bankr
XOX      0       280
*** KEXP KCON
XFL      0.3    0.1
*** xi yl xr yr
XSL      0       0      0      280
*** End of River 4
*** Start input of sediment transport data
*****
*** theta ntsefd nresponse
YST      1       1       1
*** drl dru bdi n
YSG      0.01   0.0625  0          ! silt
YSG      0.0625  0.25    0          ! fsnd
YSG      0.25    0.5     0          ! msnd
YSG      0.5     1       0          ! csnd
YSG      1       2       0          ! vcsnd
YSG      2       4       0          ! vfgrv
YSG      4       8       0          ! fgrv
YSG      8       16      0          ! mgrv
YSG      16      32      0          ! cgrv
YSG      32      64      0          ! vcgrv
YSG      64      128     0          ! scob
*** Start of River 1
*** nts
USB      3
*** TSI QSI
US3      0      57709
US3      1      57709
US3      2      57709
US3      3      57709
US3      4      57709
US3      5      57709
*** QI PISSED
USS      100     0      0.608   0.1188   0.1256   0.1275   0.0031   0.0049   0.0057   0.0058   0.0007
USS      100000  0      0.608   0.1188   0.1256   0.1275   0.0031   0.0049   0.0057   0.0058   0.0007
*** NKQS(J) non-point flow source
LNS      0
*** i i
BP1      1       2
*** PTMP
*** Layer 2
BLP      0      0.104   0.083   0.13    0.146    0.156    0.141    0.109    0.086    0.032    0.013
BLP      0      0.104   0.083   0.13    0.146    0.156    0.141    0.109    0.086    0.032    0.013
*** ttin temp
TMP      0.00    70
TMP      2400    70
*** i i
FI 1      1       2
*** crosmi n crosmax crosmi n crosmax botmi n botmax ! section 1
FIM      -9999   9999   -9999   9999    0      9999   ! section 2
FIM      -9999   9999   -9999   9999    0      9999
*** nstube wfrac
STU      1       0.8
*** imin ilength
SMN      0       0
*** ised
SEQ      6
*** i i
SA1      1       2
*** angl e1(aboangl e2(bnal t al phad al phas bl length wt dep dl ong dtrans
SAT      90      90      10      0.25    1        0        0        0        0        0
SAT      90      90      10      0.25    1        0        0        0        0        0
*** i i
CS1      1       2
*** stdep_f stdep_p concEq er_lim
CSD      0.005   0.01    0.1     0.1
CSD      0.005   0.01    0.1     0.1
*** i i
CE1      1       2
*** stpero er_stme stmero er_mass
CER      0.05    0.0678  3.00    0.4

```

```

CER      0.05  0.0678    3.00     0.4
***   fvform
CFO      1
***   densC_I  densC_f  densC_e  time_e
CSC      77.98  101.30   81.86  1000.00
***   i t
CD1      1      2
***   densi tyClay0
CDI      101.30
CDI      101.30
***   End of River      1
***   Start of River     2
***   nts
USB      0
*** 
USO
***   NKQS(J) non-point flow source
LNS      0
***   i i
BP1      1      2
***   PTMP
***   Layer      2
BLP      0  0.104  0.083  0.13  0.146  0.156  0.141  0.109  0.086  0.032  0.013
BLP      0  0.104  0.083  0.13  0.146  0.156  0.141  0.109  0.086  0.032  0.013
***   ttin  temp
TMP      0.00  70
TMP      2400  70
***   i i
FI 1     1      2
***   crosmi n  crosmax  crosmi n  crosmax  botmi n  botmax
FIM      -9999  9999  -9999  9999  0  9999  !section  1
FIM      -9999  9999  -9999  9999  0  9999  !section  2
***   nstube  wfrac
STU      1  0.8
***   i min i length
SMN      0  0
***   ised
SEQ      6
***   i i
SA1      1      2
***   angl e1(aboangl e2(bnal t  al phad  al phas  bl ength  wt  dep  dl ong  dtrans
SAT      90  90  10  0.25  1  0  0  0  0  0
SAT      90  90  10  0.25  1  0  0  0  0  0
***   i i
CS1      1      2
***   stdep_f  stdep_p  concEq  er_lim
CSD      0.005  0.01  0.1  0.1
CSD      0.005  0.01  0.1  0.1
***   i i
CE1      1      2
***   stpero er_stme  stmero er_mass
CER      0.05  0.0678  3.00  0.4
CER      0.05  0.0678  3.00  0.4
***   fvform
CFO      1
***   densC_I  densC_f  densC_e  time_e
CSC      77.98  101.30   81.86  1000.00
***   i t
CD1      1      2
***   densi tyClay0
CDI      101.30
CDI      101.30
***   End of River      2
***   Start of River     3
***   nts
USB      0
*** 
USO
***   NKQS(J) non-point flow source
LNS      0
***   i i
BP1      1      2
***   PTMP
***   Layer      2
BLP      0  0.104  0.083  0.13  0.146  0.156  0.141  0.109  0.086  0.032  0.013
BLP      0  0.104  0.083  0.13  0.146  0.156  0.141  0.109  0.086  0.032  0.013
***   ttin  temp
TMP      0.00  70
TMP      2400  70
***   i i
FI 1     1      2

```

```

*** crosmi n crosmax crosmi n crosmax botmi n botmax !section 1
FIM -9999 9999 -9999 9999 0 9999 !section 2
FIM -9999 9999 -9999 9999 0 9999 !section 2
*** nstube wfrac
STU 1 0.8
*** imin ilength
SMN 0 0
*** ised
SEQ 6
*** ii
SA1 1 2
*** angl e1(aboangl e2(bnal t al phad al phas bl ength wt dep dl ong dtrans
SAT 90 90 10 0.25 1 0 0 0 0 0
SAT 90 90 10 0.25 1 0 0 0 0 0
*** ii
CS1 1 2
*** stdep_f stdep_p concEq er_lim
CSD 0.005 0.01 0.1 0.1
CSD 0.005 0.01 0.1 0.1
*** ii
CE1 1 2
*** stpero er_stme stmero er_mass
CER 0.05 0.0678 3.00 0.4
CER 0.05 0.0678 3.00 0.4
*** fvform
CFO 1
*** densC_I densC_f densC_e time_e
CSC 77.98 101.30 81.86 1000.00
*** it
CD1 1 2
*** densi tyClay0
CDI 101.30
CDI 101.30
*** End of River 3
*** Start of River 4
*** nts
USB 0
*** USO
*** NKQS(J) non-point flow source
LNS 0
*** ii
BP1 1 2
*** PTMP
*** Layer 2
BLP 0 0.104 0.083 0.13 0.146 0.156 0.141 0.109 0.086 0.032 0.013
BLP 0 0.104 0.083 0.13 0.146 0.156 0.141 0.109 0.086 0.032 0.013
*** ttin temp
TMP 0.00 70
TMP 2400 70
*** ii
FI 1 1 2
*** crosmi n crosmax crosmi n crosmax botmi n botmax !section 1
FIM -9999 9999 -9999 9999 0 9999 !section 2
FIM -9999 9999 -9999 9999 0 9999 !section 2
*** nstube wfrac
STU 1 0.8
*** imin ilength
SMN 0 0
*** ised
SEQ 6
*** ii
SA1 1 2
*** angl e1(aboangl e2(bnal t al phad al phas bl ength wt dep dl ong dtrans
SAT 90 90 10 0.25 1 0 0 0 0 0 0
SAT 90 90 10 0.25 1 0 0 0 0 0 0
*** ii
CS1 1 2
*** stdep_f stdep_p concEq er_lim
CSD 0.005 0.01 0.1 0.1
CSD 0.005 0.01 0.1 0.1
*** ii
CE1 1 2
*** stpero er_stme stmero er_mass
CER 0.05 0.0678 3.00 0.4
CER 0.05 0.0678 3.00 0.4
*** fvform
CFO 1
*** densC_I densC_f densC_e time_e
CSC 77.98 101.30 81.86 1000.00
*** it

```

```

CD1      1      2
*** densi tyCl ay0
CDI      101.30
CDI      101.30
*** End of River      4
*** end message
END

```

## D2.2 Output Data File

Most lines in the output files are too long to be fitted into the width of the paper. In the following output data files, new lines are started with a black dot for easier reading. Sediment variables are not calculated at the initial time step.

### D2.2.1 Main output file (example2\_out.dat)

This file summarizes the dimensions that are used in the model. The total number of cross sections used in the simulation is more than the original input cross sections and interpolated cross sections. The maximum number of points in each cross section is two times of the original input due to cross section interpolation. The input data is also echoed in this output file, but is not printed here due to space limit. When an error occurs, the users should first check this file for possible warnings.

```

• **** *SUMMARY*****
•          Number of rivers=    4
•          Number of sediment class=   11
•          Number of sediment bed layers=  0
•          Number of cross sections in river 1=  2
•          Number of cross sections in river 2=  2
•          Number of cross sections in river 3=  2
•          Number of cross sections in river 4=  2
•          Total number of cross sections used in simulation= 48
•          Max number of stream tubes=  1
•          Max number of points in each cross section= 58
•          Max number of ineffective area in each cross section= 0
•          Max number of permanent ineffective area in each cross section= 0
•          Max number of levee area in each cross section= 0
•          Max number of blocked area in each cross section= 0
•          Total number of internal boundary conditions= 0
• **** *
.....
```

### D2.2.2 HEC-RAS geometry file (example2\_HEC\_RAS\_GEOMETRY.g01)

This file is the HEC-RAS geometry input file. It is updated each DTPLT time step defined in record YDT. User may use the HEC-RAS model to check the initial input geometry and the final geometry. This file is too long to be included in this section. They can be found under directory Example 2 in the GSTAR-1D distribution.

### D2.2.3 Bed profile file (example2\_OUT\_Profile.DAT)

This file contains the bed profile data. The meaning of each variable is explained in the file header.

- # output bed profile
- # t = time(hr)
- # i = cross section number

- # i dxc = original cross section number
- # xt = cross section location (ft or m)
- # q = discharge (cfs or m^3/s)
- # qlatf = lateral flow discharge (cfs or m^3/s)
- # zb0 = original thalweg elevation (ft or m)
- # zb = current thalweg elevation (ft or m)
- # z = current water surface elevation (ft or m)
- # zba = average bed elevation of the main channel (ft or m)
- # fsllope = friction slope (-)
- # topw = top width (ft or m)
- # hydtrad = hydraulic radius (ft or m)
- # d16 = sediment size d16 at bed layer 1 (mm)
- # d35 = sediment size d35 at bed layer 1 (mm)
- # d50 = sediment size d50 at bed layer 1 (mm)
- # d84 = sediment size d84 at bed layer 1 (mm)
- # tshear(j) = bed shear stress at sub-channel j (lb/ft^2 or N/m^2)
- TITLE="bed profile"
- vari ables=i, i dxc, xt, q, qlatf, zb0, zb, zba, fsllope, topw, hydtrad, d16, d35, d50, d84, tshear01
- ZONE T=" t = 0.0000, river # = 1 , river name = "

i idxc	xt	q	qlatf	zb0	zb
z	zba	fsllope	topw	hydtrad	d16
d35	d50	d84	tshear( 1)		
1 1	5280.00000	14900.0000	0.00000000	1015.00000	1015.00000
1024.88162	1017.85714	0.101493530E-02	239.526475	9.06629021	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
2 #####	4752.00000	14900.0000	0.00000000	1014.50000	1014.50000
1024.33342	1017.35714	0.103201378E-02	239.333682	9.02537583	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
3 #####	4224.00000	14900.0000	0.00000000	1014.00000	1014.00000
1023.77271	1016.85714	0.105405617E-02	239.090831	8.97379946	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
4 #####	3696.00000	14900.0000	0.00000000	1013.50000	1013.50000
1023.19559	1016.35714	0.108293584E-02	238.782352	8.90822310	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
5 #####	3168.00000	14900.0000	0.00000000	1013.00000	1013.00000
1022.59652	1015.85714	0.112154560E-02	238.386078	8.82388063	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
6 #####	2640.00000	14900.0000	0.00000000	1012.50000	1012.50000
1021.96726	1015.35714	0.117462788E-02	237.869020	8.71365611	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
7 #####	2112.00000	14900.0000	0.00000000	1012.00000	1012.00000
1021.29477	1014.85714	0.125060040E-02	237.179097	8.56627127	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
8 #####	1584.00000	14900.0000	0.00000000	1011.50000	1011.50000
1020.55659	1014.35714	0.136623881E-02	236.226358	8.36215551	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
9 #####	1056.00000	14900.0000	0.00000000	1011.00000	1011.00000
1019.70792	1013.85714	0.156159373E-02	234.831671	8.06211188	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
10 #####	528.00000	14900.0000	0.00000000	1010.50000	1010.50000
1018.63196	1013.35714	0.197066844E-02	232.527829	7.56317602	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
11 2 0.00000000	14900.0000	0.00000000	1010.00000	1010.00000	
1017.30233	1012.85714	0.283934320E-02	229.209332	6.83704588	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		

- ZONE T=" t = 0.0000, river # = 2 , river name = "

i idxc	xt	q	qlatf	zb0	zb
z	zba	fsllope	topw	hydtrad	d16
d35	d50	d84	tshear( 1)		
1 1	5280.00000	7450.00000	0.00000000	1010.00000	1010.00000
1017.30233	1012.85714	0.710259637E-03	229.204189	6.83591367	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
2 #####	4752.00000	7450.00000	0.00000000	1009.50000	1009.50000
1016.95587	1012.35714	0.661839740E-03	229.818667	6.97105017	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
3 #####	4224.00000	7450.00000	0.00000000	1009.00000	1009.00000
1016.63729	1011.85714	0.610005450E-03	230.544220	7.13021430	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		
4 #####	3696.00000	7450.00000	0.00000000	1008.50000	1008.50000
1016.34796	1011.35714	0.556145333E-03	231.387529	7.31467075	0.399065856
1.16960984	2.35737208	13.3054437	0.00000000		

- 5 ##### 3168. 00000 7450. 00000 0. 00000000 1008. 00000 1008. 00000  
1016. 08770 1010. 85714 0. 502105932E-03 232. 346634 7. 52375776 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 6 ##### 2640. 00000 7450. 00000 0. 00000000 1007. 50000 1007. 50000  
1015. 85603 1010. 35714 0. 449344693E-03 233. 420843 7. 75706759 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 7 ##### 2112. 00000 7450. 00000 0. 00000000 1007. 00000 1007. 00000  
1015. 65117 1009. 85714 0. 399298217E-03 234. 601670 8. 01248759 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 8 ##### 1584. 00000 7450. 00000 0. 00000000 1006. 50000 1006. 50000  
1015. 47137 1009. 35714 0. 352802360E-03 235. 883466 8. 28852584 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 9 ##### 1056. 00000 7450. 00000 0. 00000000 1006. 00000 1006. 00000  
1015. 31398 1008. 85714 0. 310507044E-03 237. 254210 8. 58233469 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 10 ##### 528. 00000 7450. 00000 0. 00000000 1005. 50000 1005. 50000  
1015. 17700 1008. 35714 0. 272519065E-03 238. 707709 8. 89234506 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 11 2 0. 00000000 7450. 00000 0. 00000000 1005. 00000 1005. 00000  
1015. 05748 1007. 85714 0. 238904291E-03 240. 229934 9. 21534890 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- ZONE T=" t = 0. 0000, river # = 3 , river name = "  
• # i idxc xt zba fslope topw tshear( 1) zbo hyrad zb d16  
z d35 d50  
• 1 1 5280. 00000 7450. 00000 0. 00000000 1010. 00000 1010. 00000  
1017. 30233 1012. 85714 0. 710259637E-03 229. 204189 6. 83591367 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 2 ##### 4752. 00000 7450. 00000 0. 00000000 1009. 50000 1009. 50000  
1016. 95587 1012. 35714 0. 661839740E-03 229. 818667 6. 97105017 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 3 ##### 4224. 00000 7450. 00000 0. 00000000 1009. 00000 1009. 00000  
1016. 63729 1011. 85714 0. 610005450E-03 230. 544220 7. 13021430 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 4 ##### 3696. 00000 7450. 00000 0. 00000000 1008. 50000 1008. 50000  
1016. 34796 1011. 35714 0. 556145333E-03 231. 387529 7. 31467075 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 5 ##### 3168. 00000 7450. 00000 0. 00000000 1008. 00000 1008. 00000  
1016. 08770 1010. 85714 0. 502105932E-03 232. 346634 7. 52375776 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 6 ##### 2640. 00000 7450. 00000 0. 00000000 1007. 50000 1007. 50000  
1015. 85603 1010. 35714 0. 449344693E-03 233. 420843 7. 75706759 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 7 ##### 2112. 00000 7450. 00000 0. 00000000 1007. 00000 1007. 00000  
1015. 65117 1009. 85714 0. 399298217E-03 234. 601670 8. 01248759 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 8 ##### 1584. 00000 7450. 00000 0. 00000000 1006. 50000 1006. 50000  
1015. 47137 1009. 35714 0. 352802360E-03 235. 883466 8. 28852584 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 9 ##### 1056. 00000 7450. 00000 0. 00000000 1006. 00000 1006. 00000  
1015. 31398 1008. 85714 0. 310507044E-03 237. 254210 8. 58233469 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 10 ##### 528. 00000 7450. 00000 0. 00000000 1005. 50000 1005. 50000  
1015. 17700 1008. 35714 0. 272519065E-03 238. 707709 8. 89234506 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 11 2 0. 00000000 7450. 00000 0. 00000000 1005. 00000 1005. 00000  
1015. 05748 1007. 85714 0. 238904291E-03 240. 229934 9. 21534890 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- ZONE T=" t = 0. 0000, river # = 4 , river name = "  
• # i idxc xt zba fslope topw tshear( 1) zbo hyrad zb d16  
z d35 d50  
• 1 1 5280. 00000 14900. 0000 0. 00000000 1005. 00000 1005. 00000  
1015. 05748 1007. 85714 0. 955617162E-03 240. 229934 9. 21534890 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 2 ##### 4752. 00000 14900. 0000 0. 00000000 1004. 50000 1004. 50000  
1014. 55149 1007. 35714 0. 957565225E-03 240. 205948 9. 21027237 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 3 ##### 4224. 00000 14900. 0000 0. 00000000 1004. 00000 1004. 00000  
1014. 04413 1006. 85714 0. 959960797E-03 240. 176539 9. 20404726 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 4 ##### 3696. 00000 14900. 0000 0. 00000000 1003. 50000 1003. 50000  
1013. 53511 1006. 35714 0. 962911104E-03 240. 140448 9. 19640715 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000

- 5 ##### 3168. 00000 14900. 0000 0. 00000000 1003. 00000 1003. 00000  
1013. 02403 1005. 85714 0. 966551343E-03 240. 096112 9. 18702045 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 6 ##### 2640. 00000 14900. 0000 0. 00000000 1002. 50000 1002. 50000  
1012. 51039 1005. 35714 0. 971053171E-03 240. 041579 9. 17547276 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 7 ##### 2112. 00000 14900. 0000 0. 00000000 1002. 00000 1002. 00000  
1011. 99360 1004. 85714 0. 976636395E-03 239. 974396 9. 16124341 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 8 ##### 1584. 00000 14900. 0000 0. 00000000 1001. 50000 1001. 50000  
1011. 47287 1004. 35714 0. 983585411E-03 239. 891465 9. 14367407 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 9 ##### 1056. 00000 14900. 0000 0. 00000000 1001. 00000 1001. 00000  
1010. 94721 1003. 85714 0. 992272874E-03 239. 788839 9. 12192555 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 10 ##### 528. 00000 14900. 0000 0. 00000000 1000. 50000 1000. 50000  
1010. 41536 1003. 35714 0. 100319472E-02 239. 661446 9. 09491745 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- 11 2 0. 00000000 14900. 0000 0. 00000000 1000. 00000 1000. 00000  
1009. 88000 1002. 85714 0. 101550298E-02 239. 520000 9. 06491650 0. 399065856  
1. 16960984 2. 35737208 13. 3054437 0. 00000000
- ZONE T=" t = 2400. 0000, river # = 1 , river name = "  
• # i idxc xt q qlatf zbo zb  
z zba fsl ope topw hydrad d16  
d35 d50 d84 tshear( 1 )
- 1 1 5280. 00000 14900. 0000 0. 00000000 1015. 00000 1015. 81270  
1025. 58725 1018. 56680 0. 105514870E-02 240. 000725 8. 95058880 0. 309626715  
1. 02941316 2. 21875676 12. 4653206 0. 589572252
- 2 ##### 4752. 00000 14900. 0000 0. 00000000 1014. 50000 1015. 24285  
1025. 03456 1018. 00568 0. 104871087E-02 240. 000371 8. 96704521 0. 305889106  
1. 01351668 2. 18620855 12. 5546279 0. 587052432
- 3 ##### 4224. 00000 14900. 0000 0. 00000000 1014. 00000 1014. 67632  
1024. 48528 1017. 44751 0. 104229332E-02 240. 000409 8. 98357220 0. 302000140  
0. 996944372 2. 15069915 12. 6581581 0. 584535350
- 4 ##### 3696. 00000 14900. 0000 0. 00000000 1013. 50000 1014. 11245  
1023. 93959 1016. 89178 0. 103558210E-02 240. 000045 9. 00100670 0. 297983626  
0. 979005462 2. 11103672 12. 7620312 0. 581898691
- 5 ##### 3168. 00000 14900. 0000 0. 00000000 1013. 00000 1013. 55174  
1023. 39753 1016. 33890 0. 102875813E-02 240. 000545 9. 01886567 0. 293947930  
0. 961029055 2. 06772046 12. 8329431 0. 579211211
- 6 ##### 2640. 00000 14900. 0000 0. 00000000 1012. 50000 1012. 99458  
1022. 85904 1015. 78921 0. 102198264E-02 240. 000217 9. 03676945 0. 290001199  
0. 943501145 2. 02235857 12. 8535498 0. 576538725
- 7 ##### 2112. 00000 14900. 0000 0. 00000000 1012. 00000 1012. 44142  
1022. 32395 1015. 24303 0. 101548030E-02 240. 000110 9. 05409241 0. 286267774  
0. 926975921 1. 97798847 12. 8287198 0. 573968671
- 8 ##### 1584. 00000 14900. 0000 0. 00000000 1011. 50000 1011. 89255  
1021. 79198 1014. 70060 0. 100945145E-02 240. 000120 9. 07028079 0. 282855143  
0. 911927222 1. 93775022 12. 7736355 0. 571581195
- 9 ##### 1056. 00000 14900. 0000 0. 00000000 1011. 00000 1011. 34796  
1021. 26278 1014. 16188 0. 100399880E-02 240. 000483 9. 08502257 0. 279807283  
0. 898541744 1. 90207765 12. 6988327 0. 569417706
- 10 ##### 528. 00000 14900. 0000 0. 00000000 1010. 50000 1010. 80731  
1020. 73611 1013. 62658 0. 999079819E-03 240. 000072 9. 09842792 0. 277093100  
0. 886670411 1. 87054279 12. 6053231 0. 567463990
- 11 2 0. 00000000 14900. 0000 0. 00000000 1010. 00000 1010. 27365  
1020. 20969 1013. 09705 0. 996542360E-03 240. 000030 9. 10537281 0. 275570480  
0. 880086639 1. 85326140 12. 5051771 0. 566454796
- ZONE T=" t = 2400. 0000, river # = 2 , river name = "  
• # i idxc xt q qlatf zbo zb  
z zba fsl ope topw hydrad d16  
d35 d50 d84 tshear( 1 )
- 1 1 5280. 00000 7450. 00000 0. 00000000 1010. 00000 1013. 99185  
1020. 20969 1016. 15121 0. 130473213E-02 240. 000454 5. 54078878 0. 315657045  
1. 01572153 2. 22629864 29. 1483976 0. 451299358
- 2 ##### 4752. 00000 7450. 00000 0. 00000000 1009. 50000 1013. 20064  
1019. 57750 1015. 40253 0. 119174590E-02 240. 000455 5. 69341578 0. 263113938  
0. 793491411 1. 56815738 16. 1363755 0. 423573061
- 3 ##### 4224. 00000 7450. 00000 0. 00000000 1009. 00000 1012. 56193  
1018. 95479 1014. 78311 0. 117819372E-02 239. 359802 5. 72215345 0. 257805035  
0. 771907041 1. 51545483 15. 3063711 0. 420869997
- 4 ##### 3696. 00000 7450. 00000 0. 00000000 1008. 50000 1011. 93082  
1018. 33987 1014. 17543 0. 116113031E-02 237. 947226 5. 76769871 0. 251604178  
0. 746817437 1. 45452001 14. 5776843 0. 418076049

- 5 ##### 3168. 00000 7450. 00000 0. 00000000 1008. 00000 1011. 29948  
1017. 73745 1013. 56756 0. 113801910E-02 236. 900483 5. 81796102 0. 240909213  
0. 711783283 1. 36925282 13. 4823950 0. 413325426
- 6 ##### 2640. 00000 7450. 00000 0. 00000000 1007. 50000 1010. 66682  
1017. 15275 1012. 95860 0. 110528751E-02 236. 202720 5. 87951801 0. 225542200  
0. 662837145 1. 25083946 11. 8301255 0. 405684813
- 7 ##### 2112. 00000 7450. 00000 0. 00000000 1007. 00000 1010. 03864  
1016. 58938 1012. 35282 0. 106554013E-02 235. 858800 5. 94967230 0. 208227100  
0. 606759373 1. 11682919 9. 93355380 0. 395762482
- 8 ##### 1584. 00000 7450. 00000 0. 00000000 1006. 50000 1009. 43131  
1016. 04593 1011. 76379 0. 102890836E-02 235. 744132 6. 01419767 0. 193688486  
0. 558975780 1. 00433001 8. 17628580 0. 386301286
- 9 ##### 1056. 00000 7450. 00000 0. 00000000 1006. 00000 1008. 85513  
1015. 51592 1011. 20036 0. 100365496E-02 235. 695986 6. 05994383 0. 184421036  
0. 528135069 0. 929322899 6. 74419281 0. 379686186
- 10 ##### 528. 00000 7450. 00000 0. 00000000 1005. 50000 1008. 30791  
1014. 99324 1010. 66089 0. 990309244E-03 235. 649207 6. 08505350 0. 179785295  
0. 512522018 0. 891603300 5. 89613850 0. 376189783
- 11 2 0. 00000000 7450. 00000 0. 00000000 1005. 00000 1007. 78124  
1014. 47220 1010. 14190 0. 985740927E-03 235. 218657 6. 10018977 0. 178426777  
0. 507888971 0. 880518375 5. 61050832 0. 375385848
- ZONE T=" t = 2400. 0000, river # = 3 , river name = "
- # i idxc xt q qlatf zbo zb  
z zba fsl ope topw hyrad d16  
d35 d50 d84 tshear( 1 )
- 1 1 5280. 00000 7450. 00000 0. 00000000 1010. 00000 1013. 99185  
1020. 20969 1016. 15121 0. 130473213E-02 240. 000454 5. 54078878 0. 315657045  
1. 01572153 2. 22629864 29. 1483976 0. 451299358
- 2 ##### 4752. 00000 7450. 00000 0. 00000000 1009. 50000 1013. 20064  
1019. 57750 1015. 40253 0. 119174590E-02 240. 000455 5. 69341578 0. 263113938  
0. 793491411 1. 56815738 16. 1363755 0. 423573061
- 3 ##### 4224. 00000 7450. 00000 0. 00000000 1009. 00000 1012. 56193  
1018. 95479 1014. 78311 0. 117819372E-02 239. 359802 5. 72215345 0. 257805035  
0. 7711907041 1. 51545483 15. 3063711 0. 420869997
- 4 ##### 3696. 00000 7450. 00000 0. 00000000 1008. 50000 1011. 93082  
1018. 33987 1014. 17543 0. 116113031E-02 237. 947226 5. 76769871 0. 251604178  
0. 746817437 1. 45452001 14. 5776843 0. 418076049
- 5 ##### 3168. 00000 7450. 00000 0. 00000000 1008. 00000 1011. 29948  
1017. 73745 1013. 56756 0. 113801910E-02 236. 900483 5. 81796102 0. 240909213  
0. 711783283 1. 36925282 13. 4823950 0. 413325426
- 6 ##### 2640. 00000 7450. 00000 0. 00000000 1007. 50000 1010. 66682  
1017. 15275 1012. 95860 0. 110528751E-02 236. 202720 5. 87951801 0. 225542200  
0. 662837145 1. 25083946 11. 8301255 0. 405684813
- 7 ##### 2112. 00000 7450. 00000 0. 00000000 1007. 00000 1010. 03864  
1016. 58938 1012. 35282 0. 106554013E-02 235. 858800 5. 94967230 0. 208227100  
0. 606759373 1. 11682919 9. 93355380 0. 395762482
- 8 ##### 1584. 00000 7450. 00000 0. 00000000 1006. 50000 1009. 43131  
1016. 04593 1011. 76379 0. 102890836E-02 235. 744132 6. 01419767 0. 193688486  
0. 558975780 1. 00433001 8. 17628580 0. 386301286
- 9 ##### 1056. 00000 7450. 00000 0. 00000000 1006. 00000 1008. 85513  
1015. 51592 1011. 20036 0. 100365496E-02 235. 695986 6. 05994383 0. 184421036  
0. 528135069 0. 929322899 6. 74419281 0. 379686186
- 10 ##### 528. 00000 7450. 00000 0. 00000000 1005. 50000 1008. 30791  
1014. 99324 1010. 66089 0. 990309244E-03 235. 649207 6. 08505350 0. 179785295  
0. 512522018 0. 891603300 5. 89613850 0. 376189783
- 11 2 0. 00000000 7450. 00000 0. 00000000 1005. 00000 1007. 78124  
1014. 47220 1010. 14190 0. 985740927E-03 235. 218657 6. 10018977 0. 178426777  
0. 507888971 0. 880518375 5. 61050832 0. 375385848
- ZONE T=" t = 2400. 0000, river # = 4 , river name = "
- # i idxc xt q qlatf zbo zb  
z zba fsl ope topw hyrad d16  
d35 d50 d84 tshear( 1 )
- 1 1 5280. 00000 14900. 0000 0. 00000000 1005. 00000 1003. 96786  
1014. 47220 1006. 93092 0. 822332333E-03 241. 690240 9. 60513694 0. 183525995  
0. 534964449 0. 967694879 6. 07831321 0. 493086020
- 2 ##### 4752. 00000 14900. 0000 0. 00000000 1004. 50000 1003. 54026  
1014. 03630 1006. 49748 0. 824633144E-03 241. 675134 9. 59744919 0. 184483296  
0. 538208611 0. 975379321 6. 11432582 0. 494069870
- 3 ##### 4224. 00000 14900. 0000 0. 00000000 1004. 00000 1003. 11100  
1013. 59928 1006. 06111 0. 826815585E-03 241. 666944 9. 59003721 0. 185410659  
0. 541331166 0. 982771236 5. 72716853 0. 494994882
- 4 ##### 3696. 00000 14900. 0000 0. 00000000 1003. 50000 1002. 69808  
1013. 15655 1005. 63914 0. 835066979E-03 241. 587518 9. 56339623 0. 188996218  
0. 553779562 1. 01294808 5. 53310774 0. 498545985

•	5 #####	3168. 00000	14900. 0000	0. 00000000	1003. 00000	1002. 28988
	1012. 70697	1005. 22138	0. 846650048E-03	241. 466467	9. 52682001	0. 194203189
	0. 571836653	1. 05651986	5. 49738623	0. 503528039		
•	6 #####	2640. 00000	14900. 0000	0. 00000000	1002. 50000	1001. 87805
	1012. 25045	1004. 80038	0. 859362575E-03	241. 329055	9. 48756011	0. 200199973
	0. 592484413	1. 10670500	5. 57695376	0. 508982369		
•	7 #####	2112. 00000	14900. 0000	0. 00000000	1002. 00000	1001. 45828
	1011. 78701	1004. 37661	0. 871869417E-03	241. 016933	9. 45386229	0. 206428496
	0. 613846994	1. 15908153	5. 72879750	0. 514555800		
•	8 #####	1584. 00000	14900. 0000	0. 00000000	1001. 50000	1001. 03109
	1011. 31774	1003. 93824	0. 884372555E-03	241. 042717	9. 41296086	0. 212737581
	0. 635401838	1. 21230277	5. 94006308	0. 519676731		
•	9 #####	1056. 00000	14900. 0000	0. 00000000	1001. 00000	1000. 59479
	1010. 84237	1003. 49212	0. 896175803E-03	241. 057881	9. 37524170	0. 218941138
	0. 656520936	1. 26484256	6. 17799425	0. 524502362		
•	10 #####	528. 000000	14900. 0000	0. 00000000	1000. 50000	1000. 14992
	1010. 36127	1003. 03869	0. 907300640E-03	241. 067188	9. 34039005	0. 225025715
	0. 677173788	1. 31661626	6. 43479322	0. 529039369		
•	11    2	0. 00000000	14900. 0000	0. 00000000	1000. 00000	999. 684755
	1009. 88000	1002. 56840	0. 912321923E-03	241. 082174	9. 32459001	0. 227624609
	0. 686225879	1. 33971580	6. 56041737	0. 531067371		

#### D2.2.4 Cross section geometry file (example2\_OUT\_XC.DAT)

Due to space limitation, only part of the file is printed here. Interested users may find the complete file under directory Example 2.

```

• # output cross section geometry
• # due to disk space limitation, maximum times of geometry printed is 30
• # xc = cross section number
• # t = time(hr)
• # crosloc = transversal coordinate y of bed geometry (ft or m)
• # bottom = vertical coordinate z of bed geometry (ft or m)
• TITLE="cross section geometry"
• VARIABLES=y,z
• ZONE T=" t =      0. 0000, river # =  1 , river name =
  1" , xc =
• #   crosloc      bottom
• 0. 00000000 1035. 00000
• 10. 0000000 1030. 00000
• 20. 0000000 1025. 00000
• 30. 0000000 1020. 00000
• 40. 0000000 1015. 00000
• 50. 0000000 1015. 00000
• 60. 0000000 1015. 00000
• 70. 0000000 1015. 00000
• 80. 0000000 1015. 00000
• 90. 0000000 1015. 00000
• 100. 000000 1015. 00000
• 110. 000000 1015. 00000
• 120. 000000 1015. 00000
• 130. 000000 1015. 00000
• 140. 000000 1015. 00000
• 150. 000000 1015. 00000
• 160. 000000 1015. 00000
• 170. 000000 1015. 00000
• 180. 000000 1015. 00000
• 190. 000000 1015. 00000
• 200. 000000 1015. 00000
• 210. 000000 1015. 00000
• 220. 000000 1015. 00000
• 230. 000000 1015. 00000
• 240. 000000 1015. 00000
• 250. 000000 1020. 00000
• 260. 000000 1025. 00000
• 270. 000000 1030. 00000
• 280. 000000 1035. 00000

```

- ZONE T=" t = 0. 0000, river # = 1 , river name = , xc = 2"
- # crosloc bottom
- 0. 00000000 1034. 50000
- 0. 00000000 1034. 50000
- 10. 0000000 1029. 50000
- 20. 0000000 1024. 50000
- 30. 0000000 1019. 50000
- 40. 0000000 1014. 50000
- 50. 0000000 1014. 50000
- 60. 0000000 1014. 50000
- 70. 0000000 1014. 50000
- 80. 0000000 1014. 50000
- 90. 0000000 1014. 50000
- 100. 0000000 1014. 50000
- 110. 0000000 1014. 50000
- 120. 0000000 1014. 50000
- 130. 0000000 1014. 50000
- 140. 0000000 1014. 50000
- 150. 0000000 1014. 50000
- 160. 0000000 1014. 50000
- 170. 0000000 1014. 50000
- 180. 0000000 1014. 50000
- 190. 0000000 1014. 50000
- 200. 0000000 1014. 50000
- 210. 0000000 1014. 50000
- 220. 0000000 1014. 50000
- 230. 0000000 1014. 50000
- 240. 0000000 1014. 50000
- 250. 0000000 1019. 50000
- 260. 0000000 1024. 50000
- 270. 0000000 1029. 50000
- 280. 0000000 1034. 50000
- 280. 0000000 1034. 50000
- .....

## D2.2.5 Cumulative volume of deposition file (example2\_OUT\_Volume.DAT)

- # cumulative volume of deposition in each sub-channel
- # i = cross section number
- # xt = cross section location (ft or m)
- # ssumdM = cumulative material volume of deposition in main channel (ft^3 or m^3)
- # ssumdF = cumulative material volume of deposition in floodplain (ft^3 or m^3)
- # ssumdT = cumulative material volume of deposition for entire cross section (ft^3 or m^3)
- # ssumdVM = cumulative bulk volume of deposition in main channel (ft^3 or m^3)
- # ssumdVF = cumulative bulk volume of deposition in floodplain (ft^3 or m^3)
- # ssumdVT = cumulative bulk volume of deposition for entire cross section (ft^3 or m^3)
- # ssumdCT = cumulative bulk volume of consolidation for entire cross section (ft^3 or m^3)
- # t=time(hr)
- TITLE="deposition volume"
- VARIABLES=xt,ssumdM,ssumdT,ssumdVM,ssumdVF,ssumdVT,ssumdCT
- ZONE T=" t = 0. 0000, river # = 1 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
 ssumdVT ssumdCT
- 1 0. 5280E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00
- 2 0. 4752E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00
- 3 0. 4224E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00
- 4 0. 3696E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00
- 5 0. 3168E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00
- 6 0. 2640E+04 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00 0. 0000E+00
- 0. 0000E+00 0. 0000E+00

- 7 0.2112E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1584E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1056E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5280E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 0.0000, river # = 2 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 2 0.4752E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 3 0.4224E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 4 0.3696E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 5 0.3168E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 6 0.2640E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 7 0.2112E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1584E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1056E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5280E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 0.0000, river # = 3 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 2 0.4752E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 3 0.4224E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 4 0.3696E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 5 0.3168E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 6 0.2640E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 7 0.2112E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1584E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1056E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5280E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 0.0000, river # = 4 , river name = "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 2 0.4752E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 3 0.4224E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 4 0.3696E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

- 5 0.3168E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 6 0.2640E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 7 0.2112E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 8 0.1584E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 9 0.1056E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 10 0.5280E+03 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- 11 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
- ZONE T=" t = 2400.0000, river # = 1 , river name = " " " " " " "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.3147E+05 0.0000E+00 0.3147E+05 0.5246E+05 0.0000E+00  
0.5246E+05 0.1001E-07
- 2 0.4752E+04 0.5753E+05 0.0000E+00 0.5753E+05 0.9588E+05 0.0000E+00  
0.9588E+05 0.2541E-07
- 3 0.4224E+04 0.5237E+05 0.0000E+00 0.5237E+05 0.8728E+05 0.0000E+00  
0.8728E+05 0.2407E-07
- 4 0.3696E+04 0.4742E+05 0.0000E+00 0.4742E+05 0.7904E+05 0.0000E+00  
0.7904E+05 0.2430E-07
- 5 0.3168E+04 0.4273E+05 0.0000E+00 0.4273E+05 0.7122E+05 0.0000E+00  
0.7122E+05 0.2300E-07
- 6 0.2640E+04 0.3833E+05 0.0000E+00 0.3833E+05 0.6388E+05 0.0000E+00  
0.6388E+05 0.1953E-07
- 7 0.2112E+04 0.3423E+05 0.0000E+00 0.3423E+05 0.5705E+05 0.0000E+00  
0.5705E+05 0.2303E-07
- 8 0.1584E+04 0.3047E+05 0.0000E+00 0.3047E+05 0.5078E+05 0.0000E+00  
0.5078E+05 0.2292E-07
- 9 0.1056E+04 0.2703E+05 0.0000E+00 0.2703E+05 0.4505E+05 0.0000E+00  
0.4505E+05 0.2646E-07
- 10 0.5280E+03 0.2390E+05 0.0000E+00 0.2390E+05 0.3983E+05 0.0000E+00  
0.3983E+05 0.2278E-07
- 11 0.0000E+00 0.1064E+05 0.0000E+00 0.1064E+05 0.1773E+05 0.0000E+00  
0.1773E+05 0.8817E-08
- ZONE T=" t = 2400.0000, river # = 2 , river name = " " " " " " "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.1461E+06 0.0000E+00 0.1461E+06 0.2435E+06 0.0000E+00  
0.2435E+06 0.1253E-07
- 2 0.4752E+04 0.2701E+06 0.0000E+00 0.2701E+06 0.4502E+06 0.0000E+00  
0.4502E+06 0.1893E-07
- 3 0.4224E+04 0.2595E+06 0.0000E+00 0.2595E+06 0.4326E+06 0.0000E+00  
0.4326E+06 0.1719E-07
- 4 0.3696E+04 0.2500E+06 0.0000E+00 0.2500E+06 0.4167E+06 0.0000E+00  
0.4167E+06 0.2011E-07
- 5 0.3168E+04 0.2404E+06 0.0000E+00 0.2404E+06 0.4007E+06 0.0000E+00  
0.4007E+06 0.1921E-07
- 6 0.2640E+04 0.2308E+06 0.0000E+00 0.2308E+06 0.3846E+06 0.0000E+00  
0.3846E+06 0.1644E-07
- 7 0.2112E+04 0.2214E+06 0.0000E+00 0.2214E+06 0.3690E+06 0.0000E+00  
0.3690E+06 0.1655E-07
- 8 0.1584E+04 0.2135E+06 0.0000E+00 0.2135E+06 0.3558E+06 0.0000E+00  
0.3558E+06 0.1708E-07
- 9 0.1056E+04 0.2079E+06 0.0000E+00 0.2079E+06 0.3464E+06 0.0000E+00  
0.3464E+06 0.1993E-07
- 10 0.5280E+03 0.2044E+06 0.0000E+00 0.2044E+06 0.3406E+06 0.0000E+00  
0.3406E+06 0.1885E-07
- 11 0.0000E+00 0.1013E+06 0.0000E+00 0.1013E+06 0.1689E+06 0.0000E+00  
0.1689E+06 0.8495E-08
- ZONE T=" t = 2400.0000, river # = 3 , river name = " " " " " " "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 0.1461E+06 0.0000E+00 0.1461E+06 0.2435E+06 0.0000E+00  
0.2435E+06 0.1220E-07
- 2 0.4752E+04 0.2701E+06 0.0000E+00 0.2701E+06 0.4502E+06 0.0000E+00  
0.4502E+06 0.2212E-07

- 3 0.4224E+04 0.2595E+06 0.0000E+00 0.2595E+06 0.4326E+06 0.0000E+00  
0.4326E+06 0.2224E-07
- 4 0.3696E+04 0.2500E+06 0.0000E+00 0.2500E+06 0.4167E+06 0.0000E+00  
0.4167E+06 0.1478E-07
- 5 0.3168E+04 0.2404E+06 0.0000E+00 0.2404E+06 0.4007E+06 0.0000E+00  
0.4007E+06 0.1754E-07
- 6 0.2640E+04 0.2308E+06 0.0000E+00 0.2308E+06 0.3846E+06 0.0000E+00  
0.3846E+06 0.1999E-07
- 7 0.2112E+04 0.2214E+06 0.0000E+00 0.2214E+06 0.3690E+06 0.0000E+00  
0.3690E+06 0.1218E-07
- 8 0.1584E+04 0.2135E+06 0.0000E+00 0.2135E+06 0.3558E+06 0.0000E+00  
0.3558E+06 0.1652E-07
- 9 0.1056E+04 0.2079E+06 0.0000E+00 0.2079E+06 0.3464E+06 0.0000E+00  
0.3464E+06 0.2069E-07
- 10 0.5280E+03 0.2044E+06 0.0000E+00 0.2044E+06 0.3406E+06 0.0000E+00  
0.3406E+06 0.1328E-07
- 11 0.0000E+00 0.1013E+06 0.0000E+00 0.1013E+06 0.1689E+06 0.0000E+00  
0.1689E+06 0.8065E-08
- ZONE T=" t = 2400.0000, river # = 4 , river name = " "
- # i xt ssumdM ssumdF ssumdT ssumdVM ssumdVF  
ssumdVT ssumdCT
- 1 0.5280E+04 -0.4108E+05 0.0000E+00 -0.4108E+05 -0.6847E+05 0.0000E+00 -  
0.6847E+05 0.7017E-08
- 2 0.4752E+04 -0.7626E+05 0.0000E+00 -0.7626E+05 -0.1271E+06 0.0000E+00 -  
0.1271E+06 0.1447E-07
- 3 0.4224E+04 -0.7061E+05 0.0000E+00 -0.7061E+05 -0.1177E+06 0.0000E+00 -  
0.1177E+06 0.1830E-07
- 4 0.3696E+04 -0.6369E+05 0.0000E+00 -0.6369E+05 -0.1061E+06 0.0000E+00 -  
0.1061E+06 0.2107E-07
- 5 0.3168E+04 -0.5640E+05 0.0000E+00 -0.5640E+05 -0.9399E+05 0.0000E+00 -  
0.9399E+05 0.1912E-07
- 6 0.2640E+04 -0.4939E+05 0.0000E+00 -0.4939E+05 -0.8231E+05 0.0000E+00 -  
0.8231E+05 0.2352E-07
- 7 0.2112E+04 -0.4263E+05 0.0000E+00 -0.4263E+05 -0.7104E+05 0.0000E+00 -  
0.7104E+05 0.1742E-07
- 8 0.1584E+04 -0.3716E+05 0.0000E+00 -0.3716E+05 -0.6193E+05 0.0000E+00 -  
0.6193E+05 0.1952E-07
- 9 0.1056E+04 -0.3238E+05 0.0000E+00 -0.3238E+05 -0.5396E+05 0.0000E+00 -  
0.5396E+05 0.2062E-07
- 10 0.5280E+03 -0.2825E+05 0.0000E+00 -0.2825E+05 -0.4708E+05 0.0000E+00 -  
0.4708E+05 0.2178E-07
- 11 0.0000E+00 -0.1281E+05 0.0000E+00 -0.1281E+05 -0.2134E+05 0.0000E+00 -  
0.2134E+05 0.7976E-08

## D2.2.6 Bed fraction file (example2\_OUT\_BedFraction.DAT)

- # fraction in each sub-channel
- # bed material fraction in each sub-channel
- # i = cross section number
- # xt = cross section location (ft or m)
- # pn(n,m) = bed material fraction of size m in layer n (1/1)
- # t=time(hr)
- TITLE="bed fraction"
- VARIABLES=  
i , xt, pn(01\_01), pn(01\_02), pn(01\_03), pn(01\_04), pn(01\_05), pn(01\_06), pn(01\_07), pn(01\_08), pn(01\_09),  
pn(01\_10), pn(01\_11)
- ZONE T=" t = 0.0000, river # = 1 , river name = , sub-  
channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0.5280E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 2 0.4752E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 3 0.4224E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 4 0.3696E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 5 0.3168E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01



- 3 0.4224E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 4 0.3696E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 5 0.3168E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 6 0.2640E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 7 0.2112E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 8 0.1584E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 9 0.1056E+04 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 10 0.5280E+03 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- 11 0.0000E+00 0.0000E+00 0.1040E+00 0.8300E-01 0.1300E+00 0.1460E+00  
0.1560E+00 0.1410E+00 0.1090E+00 0.8600E-01 0.3200E-01 0.1300E-01
- ZONE T=" t = 2400.0000, river # = 1 , river name = , sub-channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0.5280E+04 0.0000E+00 0.1332E+00 0.8678E-01 0.1245E+00 0.1322E+00  
0.1558E+00 0.1396E+00 0.1062E+00 0.8170E-01 0.2992E-01 0.1014E-01
- 2 0.4752E+04 0.0000E+00 0.1345E+00 0.8750E-01 0.1254E+00 0.1331E+00  
0.1518E+00 0.1387E+00 0.1061E+00 0.8202E-01 0.3051E-01 0.1035E-01
- 3 0.4224E+04 0.0000E+00 0.1359E+00 0.8827E-01 0.1264E+00 0.1340E+00  
0.1475E+00 0.1377E+00 0.1061E+00 0.8237E-01 0.3123E-01 0.1056E-01
- 4 0.3696E+04 0.0000E+00 0.1374E+00 0.8908E-01 0.1274E+00 0.1349E+00  
0.1432E+00 0.1365E+00 0.1061E+00 0.8281E-01 0.3184E-01 0.1075E-01
- 5 0.3168E+04 0.0000E+00 0.1390E+00 0.8993E-01 0.1284E+00 0.1359E+00  
0.1394E+00 0.1349E+00 0.1061E+00 0.8331E-01 0.3199E-01 0.1093E-01
- 6 0.2640E+04 0.0000E+00 0.1406E+00 0.9078E-01 0.1295E+00 0.1369E+00  
0.1367E+00 0.1330E+00 0.1060E+00 0.8386E-01 0.3154E-01 0.1110E-01
- 7 0.2112E+04 0.0000E+00 0.1421E+00 0.9162E-01 0.1306E+00 0.1379E+00  
0.1351E+00 0.1307E+00 0.1058E+00 0.8440E-01 0.3065E-01 0.1124E-01
- 8 0.1584E+04 0.0000E+00 0.1435E+00 0.9240E-01 0.1316E+00 0.1388E+00  
0.1343E+00 0.1283E+00 0.1052E+00 0.8484E-01 0.2961E-01 0.1137E-01
- 9 0.1056E+04 0.0000E+00 0.1449E+00 0.9312E-01 0.1325E+00 0.1397E+00  
0.1343E+00 0.1261E+00 0.1043E+00 0.8512E-01 0.2866E-01 0.1146E-01
- 10 0.5280E+03 0.0000E+00 0.1461E+00 0.9378E-01 0.1333E+00 0.1404E+00  
0.1345E+00 0.1244E+00 0.1030E+00 0.8516E-01 0.2789E-01 0.1152E-01
- 11 0.0000E+00 0.0000E+00 0.1468E+00 0.9415E-01 0.1337E+00 0.1408E+00  
0.1348E+00 0.1237E+00 0.1023E+00 0.8515E-01 0.2761E-01 0.1086E-01
- ZONE T=" t = 2400.0000, river # = 2 , river name = , sub-channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0.5280E+04 0.0000E+00 0.1305E+00 0.8782E-01 0.1286E+00 0.1401E+00  
0.8469E-01 0.8490E-01 0.8106E-01 0.1184E+00 0.1395E+00 0.4511E-02
- 2 0.4752E+04 0.0000E+00 0.1526E+00 0.1006E+00 0.1453E+00 0.1564E+00  
0.9605E-01 0.9626E-01 0.9103E-01 0.1452E+00 0.1184E-01 0.4771E-02
- 3 0.4224E+04 0.0000E+00 0.1555E+00 0.1022E+00 0.1474E+00 0.1583E+00  
0.9366E-01 0.9785E-01 0.9093E-01 0.1392E+00 0.1064E-01 0.4322E-02
- 4 0.3696E+04 0.0000E+00 0.1590E+00 0.1042E+00 0.1499E+00 0.1607E+00  
0.8755E-01 0.9870E-01 0.9231E-01 0.1320E+00 0.1107E-01 0.4497E-02
- 5 0.3168E+04 0.0000E+00 0.1644E+00 0.1072E+00 0.1538E+00 0.1644E+00  
0.8065E-01 0.9790E-01 0.9504E-01 0.1203E+00 0.1152E-01 0.4681E-02
- 6 0.2640E+04 0.0000E+00 0.1728E+00 0.1121E+00 0.1601E+00 0.1704E+00  
0.7518E-01 0.9460E-01 0.9714E-01 0.1008E+00 0.1201E-01 0.4877E-02
- 7 0.2112E+04 0.0000E+00 0.1843E+00 0.1186E+00 0.1686E+00 0.1786E+00  
0.7190E-01 0.8836E-01 0.9483E-01 0.7694E-01 0.1269E-01 0.5155E-02
- 8 0.1584E+04 0.0000E+00 0.1961E+00 0.1254E+00 0.1774E+00 0.1870E+00  
0.7078E-01 0.8071E-01 0.8634E-01 0.5744E-01 0.1347E-01 0.5471E-02
- 9 0.1056E+04 0.0000E+00 0.2050E+00 0.1305E+00 0.1840E+00 0.1933E+00  
0.7130E-01 0.7423E-01 0.7497E-01 0.4689E-01 0.1412E-01 0.5736E-02
- 10 0.5280E+03 0.0000E+00 0.2099E+00 0.1334E+00 0.1878E+00 0.1969E+00  
0.7249E-01 0.7055E-01 0.6547E-01 0.4294E-01 0.1460E-01 0.5931E-02
- 11 0.0000E+00 0.0000E+00 0.2114E+00 0.1343E+00 0.1890E+00 0.1981E+00  
0.7332E-01 0.6949E-01 0.6159E-01 0.4188E-01 0.1490E-01 0.6054E-02
- ZONE T=" t = 2400.0000, river # = 3 , river name = , sub-channel = 1"

- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
 pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0. 5280E+04 0. 0000E+00 0. 1305E+00 0. 8782E-01 0. 1286E+00 0. 1401E+00  
 0. 8469E-01 0. 8490E-01 0. 8106E-01 0. 1184E+00 0. 1395E+00 0. 4511E-02
- 2 0. 4752E+04 0. 0000E+00 0. 1526E+00 0. 1006E+00 0. 1453E+00 0. 1564E+00  
 0. 9605E-01 0. 9626E-01 0. 9103E-01 0. 1452E+00 0. 1184E-01 0. 4771E-02
- 3 0. 4224E+04 0. 0000E+00 0. 1555E+00 0. 1022E+00 0. 1474E+00 0. 1583E+00  
 0. 9366E-01 0. 9785E-01 0. 9093E-01 0. 1392E+00 0. 1064E-01 0. 4322E-02
- 4 0. 3696E+04 0. 0000E+00 0. 1590E+00 0. 1042E+00 0. 1499E+00 0. 1607E+00  
 0. 8755E-01 0. 9870E-01 0. 9231E-01 0. 1320E+00 0. 1107E-01 0. 4497E-02
- 5 0. 3168E+04 0. 0000E+00 0. 1644E+00 0. 1072E+00 0. 1538E+00 0. 1644E+00  
 0. 8065E-01 0. 9790E-01 0. 9504E-01 0. 1203E+00 0. 1152E-01 0. 4681E-02
- 6 0. 2640E+04 0. 0000E+00 0. 1728E+00 0. 1121E+00 0. 1601E+00 0. 1704E+00  
 0. 7518E-01 0. 9460E-01 0. 9714E-01 0. 1008E+00 0. 1201E-01 0. 4877E-02
- 7 0. 2112E+04 0. 0000E+00 0. 1843E+00 0. 1186E+00 0. 1686E+00 0. 1786E+00  
 0. 7190E-01 0. 8836E-01 0. 9483E-01 0. 7694E-01 0. 1269E-01 0. 5155E-02
- 8 0. 1584E+04 0. 0000E+00 0. 1961E+00 0. 1254E+00 0. 1774E+00 0. 1870E+00  
 0. 7078E-01 0. 8071E-01 0. 8634E-01 0. 5744E-01 0. 1347E-01 0. 5471E-02
- 9 0. 1056E+04 0. 0000E+00 0. 2050E+00 0. 1305E+00 0. 1840E+00 0. 1933E+00  
 0. 7130E-01 0. 7423E-01 0. 7497E-01 0. 4689E-01 0. 1412E-01 0. 5736E-02
- 10 0. 5280E+03 0. 0000E+00 0. 2099E+00 0. 1334E+00 0. 1878E+00 0. 1969E+00  
 0. 7249E-01 0. 7055E-01 0. 6547E-01 0. 4294E-01 0. 1460E-01 0. 5931E-02
- 11 0. 0000E+00 0. 0000E+00 0. 2114E+00 0. 1343E+00 0. 1890E+00 0. 1981E+00  
 0. 7332E-01 0. 6949E-01 0. 6159E-01 0. 4188E-01 0. 1490E-01 0. 6054E-02
- ZONE T=" t = 2400. 0000, river # = 4 , river name = , sub-channel = 1"
- # i xt pn( 1, 1) pn( 1, 2) pn( 1, 3) pn( 1, 4) pn( 1, 5)  
 pn( 1, 6) pn( 1, 7) pn( 1, 8) pn( 1, 9) pn( 1, 10) pn( 1, 11)
- 1 0. 5280E+04 0. 0000E+00 0. 2059E+00 0. 1270E+00 0. 1754E+00 0. 1796E+00  
 0. 1009E+00 0. 8481E-01 0. 6048E-01 0. 1760E-01 0. 3286E-01 0. 1544E-01
- 2 0. 4752E+04 0. 0000E+00 0. 2049E+00 0. 1265E+00 0. 1749E+00 0. 1791E+00  
 0. 1037E+00 0. 8319E-01 0. 5783E-01 0. 1755E-01 0. 3638E-01 0. 1597E-01
- 3 0. 4224E+04 0. 0000E+00 0. 2040E+00 0. 1260E+00 0. 1743E+00 0. 1787E+00  
 0. 1140E+00 0. 8302E-01 0. 5587E-01 0. 1779E-01 0. 3047E-01 0. 1583E-01
- 4 0. 3696E+04 0. 0000E+00 0. 2004E+00 0. 1242E+00 0. 1721E+00 0. 1766E+00  
 0. 1272E+00 0. 8427E-01 0. 5423E-01 0. 1798E-01 0. 2741E-01 0. 1556E-01
- 5 0. 3168E+04 0. 0000E+00 0. 1956E+00 0. 1216E+00 0. 1689E+00 0. 1737E+00  
 0. 1399E+00 0. 8760E-01 0. 5304E-01 0. 1816E-01 0. 2612E-01 0. 1527E-01
- 6 0. 2640E+04 0. 0000E+00 0. 1905E+00 0. 1189E+00 0. 1656E+00 0. 1706E+00  
 0. 1497E+00 0. 9308E-01 0. 5253E-01 0. 1844E-01 0. 2560E-01 0. 1498E-01
- 7 0. 2112E+04 0. 0000E+00 0. 1856E+00 0. 1163E+00 0. 1623E+00 0. 1676E+00  
 0. 1562E+00 0. 1001E+00 0. 5290E-01 0. 1891E-01 0. 2521E-01 0. 1474E-01
- 8 0. 1584E+04 0. 0000E+00 0. 1811E+00 0. 1138E+00 0. 1593E+00 0. 1648E+00  
 0. 1595E+00 0. 1077E+00 0. 5420E-01 0. 1967E-01 0. 2536E-01 0. 1451E-01
- 9 0. 1056E+04 0. 0000E+00 0. 1769E+00 0. 1116E+00 0. 1565E+00 0. 1623E+00  
 0. 1607E+00 0. 1148E+00 0. 5651E-01 0. 2082E-01 0. 2554E-01 0. 1432E-01
- 10 0. 5280E+03 0. 0000E+00 0. 1731E+00 0. 1095E+00 0. 1539E+00 0. 1599E+00  
 0. 1606E+00 0. 1209E+00 0. 5974E-01 0. 2241E-01 0. 2572E-01 0. 1416E-01
- 11 0. 0000E+00 0. 0000E+00 0. 1716E+00 0. 1086E+00 0. 1528E+00 0. 1588E+00  
 0. 1601E+00 0. 1234E+00 0. 6149E-01 0. 2329E-01 0. 2581E-01 0. 1409E-01

## D2.3 Final Remarks

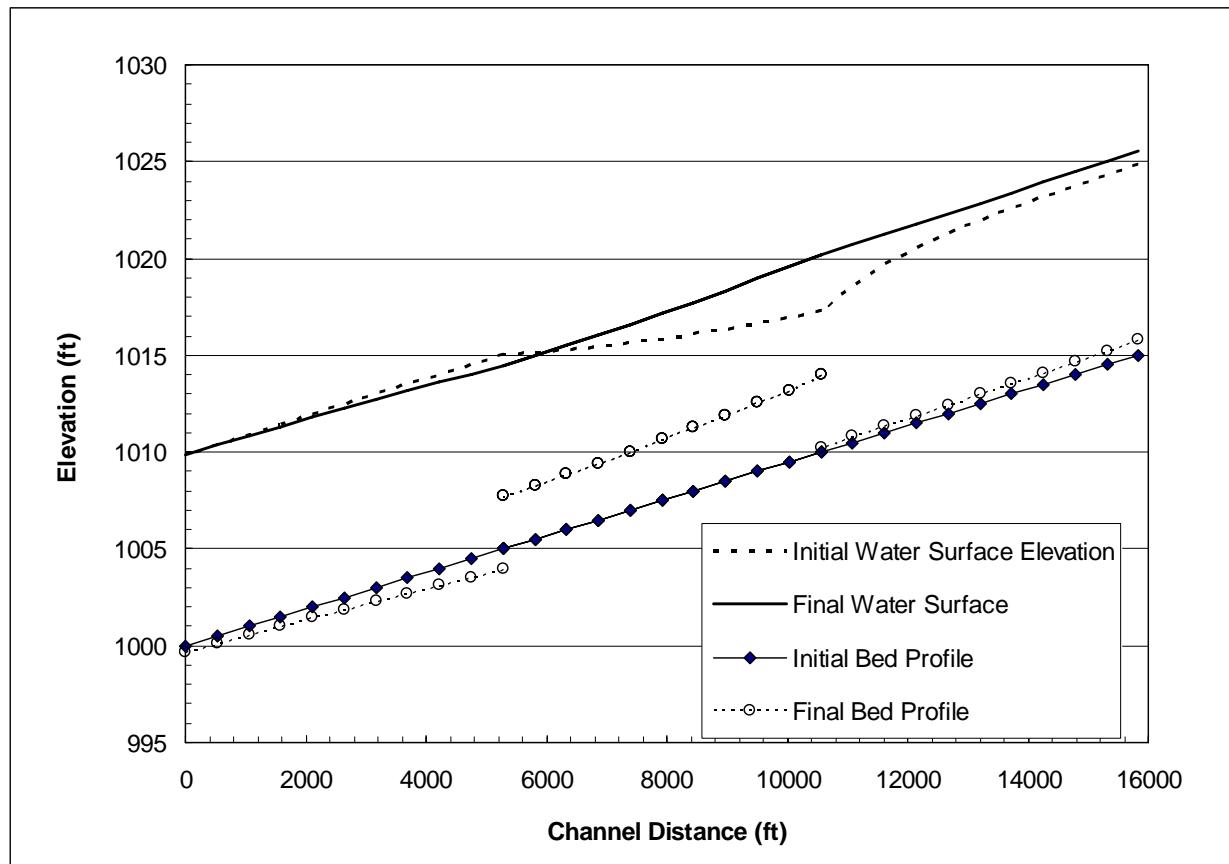


Figure D2.2 Bed elevation and water surface

Figure D2.2 shows the initial and final bed elevation and water surface elevation profiles. The middle section is the profiles for river 2 and 3, which are identical in the calculation. Due to larger conveyances and lower energy slopes in rivers 2 and 3, the sediment transport capacity is lower and sediment deposition occurs in rivers 2 and 3. The lower section experiences erosions because some of the sediments are deposited in rivers 2 and 3, and there is not enough sediment supply. The deposition in river 2 and 3 also raises the water surface elevation in river 1, resulting in sediment deposition in river 1.

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# EXAMPLE 3 CALIFORNIA AQUEDUCT

This example illustrates the use of the unsteady flow and sediment transport features of GSTAR-1D. In this example, the model was applied to the California Aqueduct near Arroyo Pasajero to study the influence of rainfall-runoff on sedimentation (Klumpp, et al., 2003). An unsteady flow and unsteady sediment model was used to simulate a duration of 2000 hrs. The studied reach of the California Aqueduct, or San Luis Canal (SLC), extends 75 miles from Check Structure 15 to Check Structure 21. The SLC was designed and built to distribute water for both agricultural and municipal uses. It was built with drain inlet structures to capture floodwaters generated west of the SLC. Rainfall-runoff is admitted to the SLC when the capacity of ponding areas or bypass structures is exceeded. The runoff carries many tons of sediment into the aqueduct. The input data includes the cross-section geometry, the six check structures and their radial gate operations. The flow in the canal prior to the flood is assumed to be 2000 cfs. In this example, only one of the six later inflows that carry storm water into the aqueduct is modeled.

The lateral inflow is modeled in terms of discharge hydrograph and sediment inflow. The bed material along the aqueduct is approximately 2% sand (non-cohesive sediment) and 98% silt and clay (cohesive sediment).

An equilibrium sediment concentration for partial deposition of 265 mg/l was observed at the downstream end of the channel, therefore an equilibrium concentration of 265 mg/l was used in the model.

The present model used a modified version of Eq. (D3.1) for surface erosion

$$Q_{se} = \begin{cases} P_{se} \left( \frac{\tau - \tau_{se}^c}{\tau_{me}^c - \tau_{se}^c} \right) & \tau \geq \tau_{se}^c \\ 0 & \tau < \tau_{se}^c \end{cases} \quad (\text{D3.1})$$

where  $\tau_{se}^c, \tau_{me}^c$  = critical surface and mass erosion shear stress, respectively.

The modified relationship is more consistent with the mass erosion rate used below. The parameters  $\tau_{se}^c$  and  $P_{se}$  are site-specific and have to be determined experimentally. Mass erosion is usually arbitrarily dependent on the model setup and its time scale used. The presented example takes the similar equation for mass erosion as the surface erosion.

$$Q_{me} = P_{me} \left( \frac{\tau - \tau_{me}^c}{\tau_{me}^c} \right) + P_{se} \quad \tau \geq \tau_{me}^c \quad (\text{D3.2})$$

where  $Q_{me}$  = mass erosion rate,

$\tau$  and  $\tau_{me}^c$  = bed shear stress and critical mass erosion shear stress, respectively, and

$P_{me}$  = mass erosion constant.

Because physical experiments were not performed, the cohesive sediment transport parameters were calibrated to the available observations. The critical shear stresses for full deposition, partial deposition, surface erosion, and mass erosion were determined from the observations in the channel during various discharges. These parameters are listed in Table D3.1.

Process	Discharge (cfs)	Shear Stress (lb/ft <sup>2</sup> )
Full deposition	2,000	0.003
Partial deposition	2,000	0.003
Surface erosion	8,000	0.005
Mass erosion	>>10,000	0.01

Table D3.1.— Cohesive sediment parameters for erosion and deposition

The surface erosion rate was calibrated and found to equal 0.3 lb/ft<sup>2</sup>/hr. The settling velocities are found in Figure 3.4.

The parameters used in this example are listed in Table D3.2.

Point	C (mg/l)	V (mm/s)
1	200	0.2
2	6,000	0.2
3	20,000	0.35
4	100,000	0.35

Table D3.2.— Cohesive sediment parameters for fall velocity used in the GSTAR-1D example.

## D3.1 Input Data File (Example3.txt)

The files shown in this and the next sections are part of the main GSTAR-1D distribution package. They can be found under directory Example3.

```

YTT PROBLEM San Luis Canal - Flooding of Arroyo Pasajero
YTT lateral inflows and radial gates
YTT EOM
*****
*** Note: This is a simplified version of the datafile used to simulate ***
*** the San Luis Canal. It may not represent the actual flow and ***
*** geological conditions at the site, and is used here only as an example ***
*** of input data as it might be used in a GSTARS-1D simulation. ***
*** This file was constructed for didactic purposes only. ***
*****
*** nriv      nf      nlay
YNR      1        4        2
*** isolve    isolves   EPSY      F1      XFACT    METRIC    YZ
YSL      3        2  1.00E-03      1        1        0        1
*** KFLP      qmin
YFP      0        0
*** THE      iHotSt
YTM      2000     0
*** TDT      DT      DTPLT    xcplt
YDT      0       0.01      100      36          37          38          43

```

YDT 1000 0.01 100 36 37 38 43  
 YDT 1001 0.05 200 36 37 38 43  
 \*\*\* Start of River 1  
 \*\*\* KU(J)  
 UFB 2  
 \*\*\* T1 ST1  
 U02 0 2000 ! 5/21/01 0:00  
 U02 650 2000  
 U02 660 5600  
 U02 670 6000  
 U02 680 6400  
 U02 690 6800  
 U02 700 7200  
 U02 740 7600  
 U02 760 8000  
 U02 770 8300  
 U02 3000 8300  
 \*\*\* KD(J)  
 DFB 3  
 \*\*\* FLOWR ELEVR  
 D03 0.00 289.00  
 D03 100.00 305.00  
 D03 500.00 306.00  
 D03 1000.00 308.00  
 D03 2500.00 314.00  
 D03 10000.00 315.00  
 D03 20000.00 316.00  
 \*\*\* NKI(J) b.c. for internal station  
 INF 8  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 15  
 IFB 9 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 100.00 28.00 303.50 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 326.00 325.00 0.10 0.10 28.00 2.00 3.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 16  
 IFB 23 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 100.00 28.00 298.00 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 324.00 323.00 0.10 0.10 28.00 2.00 5.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 17  
 IFB 33 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 100.00 28.00 296.10 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 321.00 319.50 0.10 0.10 27.00 2.00 3.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 18  
 IFB 45 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 100.00 27.00 292.30 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 320.00 318.00 0.10 0.10 26.00 2.00 3.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 19  
 IFB 57 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 75.00 27.00 292.30 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 318.00 317.00 0.10 0.10 25.00 2.00 5.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 20  
 IFB 68 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE  
 I08 0.70 75.00 27.00 291.20 0.16 0.72 0.62 3 0  
 0  
 \*\*\* WSEOpen WSECclose OpenRate CloseRate MaxOpen MinOpen InitOpen  
 I8B 317.00 313.00 0.10 0.10 25.00 2.00 7.00  
 \*\*\* NXI(J,nk) KI(J,nk) XTI(J,NK) Check 21  
 IFB 79 8 0  
 \*\*\* C W T Zsp TE BE HE Cw GDIR  
 GTYPE

```

I08      0.70     75.00    30.00   289.50     0.16     0.72     0.62      3      0
0
***      WSEOpen  WSECclose  OpenRate CloseRate MaxOpen  MinOpen InitOpen
I8B      315.00   311.00    0.10     0.10    24.00    2.00    24.00
***      NXI(J,nk) KI(J,nk) XTI(J,NK)          Lateral Weir
IFB      76        8        100
***      C         W         T       Zsp      TE      BE      HE      Cw      GDIR
GTYPE
I08      0.70     90.00    25.00   309.00     0.00     0.00     0.60      3.7     1
1
***      WSEOpen  WSECclose  OpenRate CloseRate MaxOpen  MinOpen InitOpen
I8B      314.00   313.00    0.10     0.10    7.00     0.00     0.00
***      NKQF(J) non-point flow source
LNF      1
***      X1QF(J,nk) X2QF(J,nk)          Lateral 1
LFL      192414.5 180000
***      t3        ST3
LFD      199.99    0           !
LFD      200        2           ! 5/28/01 0:00
LFD      284        905          ! 5/31/01 12:00
LFD      288        937          ! 5/31/01 16:00
LFD      292        969          ! 5/31/01 20:00
LFD      296        1002         ! 6/1/01 0:00
LFD      300        1002         ! 6/1/01 4:00
LFD      304        1002         ! 6/1/01 8:00
LFD      308        1002         ! 6/1/01 12:00
LFD      312        969          ! 6/1/01 16:00
LFD      316        969          ! 6/1/01 20:00
LFD      320        969          ! 6/2/01 0:00
LFD      324        937          ! 6/2/01 4:00
LFD      404        937          ! 6/5/01 12:00
LFD      408        905          ! 6/5/01 16:00
LFD      412        874          ! 6/5/01 20:00
LFD      416        814          ! 6/6/01 0:00
LFD      420        756          ! 6/6/01 4:00
LFD      424        684          ! 6/6/01 8:00
LFD      428        520          ! 6/6/01 12:00
LFD      452        305          ! 6/7/01 12:00
LFD      456        242          ! 6/7/01 16:00
LFD      460        242          ! 6/7/01 20:00
LFD      464        242          ! 6/8/01 0:00
LFD      468        242          ! 6/8/01 4:00
LFD      472        242          ! 6/8/01 8:00
LFD      476        184          ! 6/8/01 12:00
LFD      596        184          ! 6/13/01 12:00
LFD      600        0           !
***      FLDST     ZDI      QDI ----- cross section      1beginning      of
pool     15        MP      95.11
XIN      0         0
***      xt        bec      ninterp   iHotC
XST      395338.09 0         0         0
***      station elevation data
XSP      0         336.5      100      336.5      159.8      306.6      244.8      306.6      304.6
336.5
XSP      404.6     336.5
***      xloc_rcoef rcoef
XRH      0         0.015      100      0.015      304.6      0.015
***      locl_ob    locl_ob
XOX      100        304.6
***      fkec
XFL      0.3        0.1
***      xl        yl      xr      yr
XSL      100        336.5      304.6      336.5
***      FLDST     ZDI      QDI ----- cross section      2
XIN      0         0         0
***      location   bec      ninterp   iHotC
XST      386230.91 0         0         0
***      station elevation data
XSP      0         335.71     100      335.71      159.8      305.81      244.8      305.81      304.6
335.71
XSP      404.6     335.71
***      xloc_rcoef rcoef
XRH      0         0.015      100      0.015      304.6      0.015
***      bankl    bankr
XOX      100        304.6
***      fkec
XFL      0.3        0.1
***      xl        yl      xr      yr
XSL      100        335.71      304.6      335.71
***      FLDST     ZDI      QDI ----- cross section      3
XIN      0         0         0

```

```

*** location      bec   ninterp   iHotC
XST 369003.09      0       0       0
*** station elevation      data
XSP      0     335.23      100    335.23    161.8    304.33    246.8    304.33    308.6
335.23
XSP      408.6    335.23
*** xloc_rcoef   rcoef
XRH      0     0.015      100    0.015    308.6    0.015
*** bankl      bankr
XOX      100    308.6
*** fkec
XFL      0.3     0.1
*** xl        yl      xr      yr
XSL      100    335.23    308.6    335.23
*** FLDST      ZDI      QDI -----
XIN      0       0       0       cross section      4
*** location      bec   ninterp   iHotC
XST 346361.44      0       0       0
*** station elevation      data
XSP      0     334.96      100    334.96    165.13    302.39    250.13    302.39    315.27
334.96
XSP      415.27    334.96
*** xloc_rcoef   rcoef
XRH      0     0.015      100    0.015    315.27    0.015
*** bankl      bankr
XOX      100    315.27
*** fkec
XFL      0.3     0.1
*** xl        yl      xr      yr
XSL      100    334.96    315.27    334.96
*** FLDST      ZDI      QDI -----
XIN      0       0       0       cross section      5
*** location      bec   ninterp   iHotC
XST 334957.12      0       0       0
*** station elevation      data
XSP      0     334.26      100    334.26    165.72    301.4     250.72    301.4     316.44
334.26
XSP      416.44    334.26
*** xloc_rcoef   rcoef
XRH      0     0.015      100    0.015    316.44    0.015
*** bankl      bankr
XOX      100    316.44
*** fkec
XFL      0.3     0.1
*** xl        yl      xr      yr
XSL      100    334.26    316.44    334.26
*** FLDST      ZDI      QDI -----
XIN      0       0       0       cross section      6
*** location      bec   ninterp   iHotC
XST 326362.12      0       0       0
*** station elevation      data
XSP      0     333.46      100    333.46    165.62    300.65    250.62    300.65    316.24
333.46
XSP      416.24    333.46
*** xloc_rcoef   rcoef
XRH      0     0.015      100    0.015    316.24    0.015
*** bankl      bankr
XOX      100    316.24
*** fkec
XFL      0.3     0.1
*** xl        yl      xr      yr
XSL      100    333.46    316.24    333.46
*** FLDST      ZDI      QDI -----
XIN      0       0       0       cross section      7
*** location      bec   ninterp   iHotC
XST 324603.12      0       0       0
*** station elevation      data
XSP      0     334.5      121.22    334.5     160.58    301.7     255.78    301.7     295.14
334.5
XSP      416.36    334.5
*** xloc_rcoef   rcoef
XRH      0     0.015      121.22    0.015    295.14    0.015
*** bankl      bankr
XOX      121.22    295.14
*** fkec
XFL      0.3     0.1
*** xl        yl      xr      yr
XSL      121.22    334.5     295.14    334.5
*** FLDST      ZDI      QDI -----
XIN      0       0       0       cross section      8
*** location      bec   ninterp   iHotC

```

XST	324553.12	0	0	0					
***	station	elevation							
XSP	0	336	147.75	336	154.31	303.2	262.26	303.2	268.82
336									
XSP	416.56	336							
***	xloc_rcoef	rcoef							
XRH	0	0.015	147.75	0.015	268.82	0.015			
***	bankl	bankr							
XOX	147.75	268.82							
***	fkec								
XFL	0.3	0.1							
***	xl	yl	xr	yr					
XSL	147.75	336	268.82	336					
***	FLDST	ZDI	QDI -----						
XIN	0	0	0						
***	location	bec	ninterp	iHotC					
XST	324433.12	0	0	0					
***	station	elevation							
XSP	0	336.3	155.3	336.3	155.5	302.98	237.3	302.98	237.5
336.3									
XSP	395.6	336.3							
***	xloc_rcoef	rcoef							
XRH	0	0.015	0	0.015	0	0.015			
***	bankl	bankr							
XOX	155.3	237.5							
***	fkec								
XFL	0.3	0.1							
***	xl	yl	xr	yr					
XSL	0.00E+00	336.3	0.00E+00	336.3					
***	FLDST	ZDI	QDI -----						
XIN	0	0	0						
***	location	bec	ninterp	iHotC					
XST	324405.62	0	0	0					
***	station	elevation							
XSP	0	335.55	139.79	335.55	156.19	302.75	257.81	302.75	274.21
335.55									
XSP	414	335.55							
***	xloc_rcoef	rcoef							
XRH	0	0.015	139.79	0.015	274.21	0.015			
***	bankl	bankr							
XOX	139.79	274.21							
***	fkec								
XFL	0.3	0.1							
***	xl	yl	xr	yr					
XSL	139.79	335.55	274.21	335.55					
***	FLDST	ZDI	QDI -----						
XIN	0	0	0						
***	location	bec	ninterp	iHotC					
XST	324336.88	0	0	0					
***	station	elevation							
XSP	0	333.67	106.63	333.67	164.03	300.88	243.47	300.88	300.87
333.67									
XSP	407.5	333.67							
***	xloc_rcoef	rcoef							
XRH	0	0.015	106.63	0.015	300.87	0.015			
***	bankl	bankr							
XOX	106.63	300.87							
***	fkec								
XFL	0.3	0.1							
***	xl	yl	xr	yr					
XSL	106.63	333.67	300.87	333.67					
***	FLDST	ZDI	QDI -----						
XIN	0	0	0						
***	location	bec	ninterp	iHotC					
XST	323383.12	0	0	0					
***	station	elevation							
XSP	0	333.96	142.6	333.96	168.84	300.5	239.04	300.5	265.28
333.96									
XSP	411	333.96							
***	xloc_rcoef	rcoef							
XRH	0	0.015	142.6	0.015	265.28	0.015			
***	bankl	bankr							
XOX	142.6	265.28							
***	fkec								
XFL	0.3	0.1							
***	xl	yl	xr	yr					
XSL	142.6	333.96	265.28	333.96					
***	FLDST	ZDI	QDI -----						
XIN	0	0	0						
***	location	bec	ninterp	iHotC					
XST	322443.12	0	0	0					

```

***      station elevation      data
XSP      0      334.4      156.8    334.4    170.72    299.6    239.32    299.6    253.24
334.4
XSP      414.2      334.4
***      xloc_rcoef      rcoef
XRH      0      0.015      156.8    0.015    253.24    0.015
***      bankl      bankr
XOX      156.8      253.24
***      fkec
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      156.8      334.4      253.24      334.4
***      FLDST      ZDI      QDI -----
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      321371.44      0      0      0
***      station      elevation      data
XSP      0      334.3      100      334.3      169.6    299.53    244.6    299.53    314.2
334.3
XSP      414.2      334.3
***      xloc_rcoef      rcoef
XRH      0      0.015      100      0.015    314.2    0.015
***      bankl      bankr
XOX      100      314.2
***      fkec
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      100      334.3      314.2      334.3
***      FLDST      ZDI      QDI -----
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      316813.09      0      0      0
transitio MP109.90
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      316813.09      0      0      0
***      station      elevation      data
XSP      0      333.8      100      333.8      169.6    299.2    244.6    299.2    314.2
333.8
XSP      414.2      333.8
***      xloc_rcoef      rcoef
XRH      0      0.015      100      0.015    314.2    0.015
***      bankl      bankr
XOX      100      314.2
***      fkec
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      100      333.8      314.2      333.8
***      FLDST      ZDI      QDI -----
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      304953.09      0      0      0
***      station      elevation      data
XSP      0      335.33      100      335.33      169.6    300.53    244.6    300.53    314.2
335.33
XSP      414.2      335.33
***      xloc_rcoef      rcoef
XRH      0      0.015      100      0.015    314.2    0.015
***      bankl      bankr
XOX      100      314.2
***      fkec
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      100      335.33      314.2      335.33
***      FLDST      ZDI      QDI -----
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      292345.31      0      0      0
***      station      elevation      data
XSP      0      332.88      100      332.88      168.71    298.52    243.71    298.52    312.42
332.88
XSP      412.42      332.88
***      xloc_rcoef      rcoef
XRH      0      0.015      100      0.015    312.42    0.015
***      bankl      bankr
XOX      100      312.42
***      fkec
XFL      0.3      0.1
***      xl      yl      xr      yr
XSL      100      332.88      312.42      332.88
***      FLDST      ZDI      QDI -----
XIN      0      0      0
***      location      bec      ninterp      iHotC
XST      276900.84      0      0      0

```

```

***      station elevation      data
XSP      0      330.82      100    330.82    166.49    297.58    241.49    297.58    307.98
330.82
XSP      407.98      330.82
***  xloc_rcoef      rcoef
XRH      0      0.015      100    0.015    307.98    0.015
***  bankl      bankr
XOX      100    307.98
***  fkec
XFL      0.3      0.1
***  xl      yl      xr      yr
XSL      100    330.82    307.98    330.82
***  FLDST      ZDI      QDI -----
XIN      0      0      0
***  location      bec      ninterp      iHotC
XST      266927.06    0      0      0
***  station elevation      data
XSP      0      328.96      100    328.96    165.6     296.16    240.6     296.16    306.2
328.96
XSP      406.2      328.96
***  xloc_rcoef      rcoef
XRH      0      0.015      100    0.015    306.2     0.015
***  bankl      bankr
XOX      100    306.2
***  fkec
XFL      0.3      0.1
***  xl      yl      xr      yr
XSL      100    328.96    306.2     328.96
***  FLDST      ZDI      QDI -----
XIN      0      0      0
***  location      bec      ninterp      iHotC
XST      257937.06    0      0      0
***  station elevation      data
XSP      0      328.36      100    328.36    165.6     295.56    240.6     295.56    306.2
328.36
XSP      406.2      328.36
***  xloc_rcoef      rcoef
XRH      0      0.015      100    0.015    306.2     0.015
***  bankl      bankr
XOX      100    306.2
***  fkec
XFL      0.3      0.1
***  xl      yl      xr      yr
XSL      100    328.36    306.2     328.36
***  FLDST      ZDI      QDI -----
XIN      0      0      0
***  location      bec      ninterp      iHotC
XST      252523.05    0      0      0
***  station elevation      data
XSP      0      328.1      109.57    328.1     162.05    295.76    244.15    295.76    296.63
328.1
XSP      406.2      328.1
***  xloc_rcoef      rcoef
XRH      0      0.015      109.57    0.015    296.63     0.015
***  bankl      bankr
XOX      109.57    296.63
***  fkec
XFL      0.3      0.1
***  xl      yl      xr      yr
XSL      109.57    328.1     296.63    328.1
***  FLDST      ZDI      QDI -----
XIN      0      0      0
***  location      bec      ninterp      iHotC
XST      252473.06    0      0      0
***  station elevation      data
XSP      0      328.34      133.5     328.34    153.18     297.16    253.03    297.16    272.71
328.34
XSP      406.2      328.34
***  xloc_rcoef      rcoef
XRH      0      0.015      133.5     0.015    272.71     0.015
***  bankl      bankr
XOX      133.5     272.71
***  fkec
XFL      0.3      0.1
***  xl      yl      xr      yr
XSL      133.5     328.34    272.71    328.34
***  FLDST      ZDI      QDI -----
XIN      0      0      0
***  location      bec      ninterp      iHotC
XST      252333.06    0      0      0
***  station elevation      data

```

XSP	0	329	155.3	329	155.5	296.68	237.3	296.68	237.5
329									
XSP	400	329							
*** xloc_rcoef	rcoef								
XRH	0	0.015		0	0.015		0	0.015	
*** bankl	bankr								
XOX	155.3	237.5							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	0.00E+00	329	0.00E+00	329					
*** FLDST	ZDI	QDI	-----						
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	252264.31	0	0	0					
*** station	elevation	data							
XSP	0	328.12	117.94	328.12	158.94	296.19	247.26	296.19	288.26
328.12									
XSP	406.2	328.12							
*** xloc_rcoef	rcoef								
XRH	0	0.015	117.94	0.015	288.26	0.015			
*** bankl	bankr								
XOX	117.94	288.26							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	117.94	328.12	288.26	328.12					
*** FLDST	ZDI	QDI	-----						
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	246866.16	0	0	0					
*** station	elevation	data							
XSP	0	327.72	100	327.72	165.91	294.76	240.91	294.76	306.82
327.72									
XSP	406.82	327.72							
*** xloc_rcoef	rcoef								
XRH	0	0.015	100	0.015	306.82	0.015			
*** bankl	bankr								
XOX	100	306.82							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	327.72	306.82	327.72					
*** FLDST	ZDI	QDI	-----						
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	233473.89	0	0	0					
*** station	elevation	data							
XSP	0	327.25	100	327.25	166.68	293.92	241.68	293.92	308.35
327.25									
XSP	408.35	327.25							
*** xloc_rcoef	rcoef								
XRH	0	0.015	100	0.015	308.35	0.015			
*** bankl	bankr								
XOX	100	308.35							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	327.25	308.35	327.25					
*** FLDST	ZDI	QDI	-----						
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	220081.62	0	0	0					
*** station	elevation	data							
XSP	0	326.79	100	326.79	167.45	293.07	242.45	293.07	309.89
326.79									
XSP	409.89	326.79							
*** xloc_rcoef	rcoef								
XRH	0	0.015	100	0.015	309.89	0.015			
*** bankl	bankr								
XOX	100	309.89							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	326.79	309.89	326.79					
*** FLDST	ZDI	QDI	-----						
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	211863.16	0	0	0					
*** station	elevation	data							

XSP	0	327.08	100	327.08	167.6	292.52	242.6	292.52	310.2
327.08									
XSP	410.2	327.08							
*** xloc_rcoef		rcoef							
XRH	0	0.015	100	0.015	310.2	0.015			
*** bankl		bankr							
XOX	100	310.2							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	327.08	310.2	327.08					
*** FLDST	ZDI	QDI	-----		cross	section	29		
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	202963.16	0	0	0					
*** station	elevation	data							
XSP	0	327.7	100	327.7	167.6	291.9	242.6	291.9	310.2
327.7									
XSP	410.2	327.7							
*** xloc_rcoef		rcoef							
XRH	0	0.015	100	0.015	310.2	0.015			
*** bankl		bankr							
XOX	100	310.2							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	327.7	310.2	327.7					
*** FLDST	ZDI	QDI	-----		cross	section	30		
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	195743.16	0	0	0					
*** station	elevation	data							
XSP	0	328.2	100	328.2	167.6	291.4	242.6	291.4	310.2
328.2									
XSP	410.2	328.2							
*** xloc_rcoef		rcoef							
XRH	0	0.015	100	0.015	310.2	0.015			
*** bankl		bankr							
XOX	100	310.2							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	100	328.2	310.2	328.2					
*** FLDST	ZDI	QDI	-----		cross	section	31		
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	195063.16	0	0	0					
*** station	elevation	data							
XSP	0	326.97	118.13	326.97	161.15	293.11	249.05	293.11	292.07
326.97									
XSP	410.2	326.97							
*** xloc_rcoef		rcoef							
XRH	0	0.015	118.13	0.015	292.07	0.015			
*** bankl		bankr							
XOX	118.13	292.07							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	118.13	326.97	292.07	326.97					
*** FLDST	ZDI	QDI	-----		cross	section	32		
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	195013.16	0	0	0					
*** station	elevation	data							
XSP	0	325.43	140.79	325.43	153.08	295.25	257.12	295.25	269.41
325.43									
XSP	410.2	325.43							
*** xloc_rcoef		rcoef							
XRH	0	0.015	140.79	0.015	269.41	0.015			
*** bankl		bankr							
XOX	140.79	269.41							
*** fkec									
XFL	0.3	0.1							
*** xl	yl	xr	yr						
XSL	140.79	325.43	269.41	325.43					
*** FLDST	ZDI	QDI	-----		cross	section	33	check	17
XIN	0	0	0						
*** location	bec	ninterp	iHotC						
XST	194883.14	0	0	0					
*** station	elevation	data							

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XSP          0      327     155.3      327     155.5    295.45    237.3    295.45    237.5
327
XSP        410.2      327
***  xloc_rcoef   rcoef
XRH          0     0.015      0     0.015      0     0.015
***  bankl   bankr
XOX        155.3     237.5
***  fkec
XFL          0.3      0.1
***  xl       yl      xr      yr
XSL      0.00E+00      327  0.00E+00      327
***  FLDST     ZDI      QDI ----- cross section      34
XIN          0       0       0
***  location   bec  ninterp   iHotC
XST  194873.16      0       0       0
***  station elevation data
XSP          0     324.57     145.32     324.57     150.92    295.66    257.74    295.66    263.79
324.57
XSP        409.11     324.57
***  xloc_rcoef   rcoef
XRH          0     0.015     145.32     0.015     263.79     0.015
***  bankl   bankr
XOX        145.32     263.79
***  fkec
XFL          0.3      0.1
***  xl       yl      xr      yr
XSL      145.32     324.57     263.79     324.57
***  FLDST     ZDI      QDI ----- cross section      35
XIN          0       0       0
***  location   bec  ninterp   iHotC
XST  194823.17      0       0       0
***  station elevation data
XSP          0     323.33     122.66     323.33     156.26    293.48    244.67    293.48     281
323.33
XSP        403.65     323.33
***  xloc_rcoef   rcoef
XRH          0     0.015     122.66     0.015     281     0.015
***  bankl   bankr
XOX        122.66     281
***  fkec
XFL          0.3      0.1
***  xl       yl      xr      yr
XSL      122.66     323.33     281     323.33
***  FLDST     ZDI      QDI ----- cross section      36 First section
in      Pool        18       MP      133
XIN          0       0       0
***  location   bec  ninterp   iHotC
XST  194773.16      0       0       0
***  station elevation data
XSP          0     322.1      100     322.1     161.6    291.3    231.6    291.3    298.2
322.1
XSP        398.2     322.1
***  LOCBPU(1:n)
XBD          2       5
***  xloc_rcoef   rcoef
XRH          0     0.015      100     0.015     298.2     0.015
***  bankl   bankr
XOX        100     298.2
***  fkec
XFL          0.3      0.1
***  xl       yl      xr      yr
XSL      100     322.1     298.2     322.1
***  FLDST     ZDI      QDI ----- cross section      37
XIN          0       0       0
***  location   bec  ninterp   iHotC
XST  189305.5      0       0       0
***  station elevation data
XSP          0     321.94      100     321.94     161.6    291.14    231.6    291.14    298.2
321.94
XSP        398.2     321.94
***  LOCBPU(1:n)
XBU          2       5
***  LOCBPD(1:n)
XBD          2       5
***  xloc_rcoef   rcoef
XRH          0     0.015      100     0.015     298.2     0.015
***  bankl   bankr
XOX        100     298.2
***  fkec
XFL          0.3      0.1
***  xl       yl      xr      yr

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XSL      100    321.94    298.2    321.94      cross section      38
***     FLDST      ZDI      QDI -----      cross section      38
XIN      0        0        0
***     location    bec    ninterp    iHotC
XST      184461    0        0        0
***     station elevation data
XSP      0        322.47    100      322.47    161.6    291.67    231.6    291.67    298.2
322.47
XSP      398.2    322.47
***     LOCBPU(1:n)
XBU      2        5
***     LOCBPU(1:n)
XBD      2        5
***     xloc_rcoef rcoef
XRH      0        0.015    100      0.015    298.2    0.015
***     bankl      bankr
XOX      100      298.2
***     fkec
XFL      0.3      0.1
***     xl         yl       xr       yr
XSL      100      322.47    298.2    322.47      cross section      39
***     FLDST      ZDI      QDI -----      cross section      39
XIN      0        0
***     location    bec    ninterp    iHotC
XST      178659    0        0        0
***     station elevation data
XSP      0        322.8     100      322.8     161.6    292      231.6    292      298.2
322.8
XSP      398.2    322.8
***     LOCBPU(1:n)
XBU      2        5
***     LOCBPU(1:n)
XBD      2        5
***     xloc_rcoef rcoef
XRH      0        0.015    100      0.015    298.2    0.015
***     bankl      bankr
XOX      100      298.2
***     fkec
XFL      0.3      0.1
***     xl         yl       xr       yr
XSL      100      322.8     298.2    322.8      cross section      40
***     FLDST      ZDI      QDI -----      cross section      40
XIN      0        0
***     location    bec    ninterp    iHotC
XST      169109.94 0        0        0
***     station elevation data
XSP      0        323.12    100      323.12    161.6    292.32    231.6    292.32    298.2
323.12
XSP      398.2    323.12
***     LOCBPU(1:n)
XBU      2        5
***     LOCBPU(1:n)
XBD      2        5
***     xloc_rcoef rcoef
XRH      0        0.015    100      0.015    298.2    0.015
***     bankl      bankr
XOX      100      298.2
***     fkec
XFL      0.3      0.1
***     xl         yl       xr       yr
XSL      100      323.12    298.2    323.12      cross section      41
***     FLDST      ZDI      QDI -----      cross section      41
XIN      0        0
***     location    bec    ninterp    iHotC
XST      159560.88 0        0        0
***     station elevation data
XSP      0        323.45    100      323.45    161.6    292.65    231.6    292.65    298.2
323.45
XSP      398.2    323.45
***     LOCBPU(1:n)
XBU      2        5
***     LOCBPU(1:n)
XBD      2        5
***     xloc_rcoef rcoef
XRH      0        0.015    100      0.015    298.2    0.015
***     bankl      bankr
XOX      100      298.2
***     fkec
XFL      0.3      0.1
***     xl         yl       xr       yr
XSL      100      323.45    298.2    323.45

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***      FLDST      ZDI      QDI ----- cross section    42
XIN      0          0          0
***      location    bec      ninterp   iHotC
XST      150011.81   0          0          0
***      station    elevation data
XSP      0          323.77   100       323.77   161.6    292.97   231.6    292.97   298.2
323.77
XSP      398.2      323.77
***      LOCBPU(1:n)
XBU      2          5
***      LOCBPU(1:n)
XBD      2          5
***      xloc_rcoef rcoef
XRH      0          0.015     100       0.015    298.2    0.015
***      bankl      bankr
XOX      100        298.2
***      fkec
XFL      0.3        0.1
***      xl         yl        xr        yr
XSL      100        323.77   298.2    323.77
***      FLDST      ZDI      QDI ----- cross section    43
XIN      0          0          0
***      location    bec      ninterp   iHotC
XST      146162.19   0          0          0
***      station    elevation data
XSP      0          324.23   113.15   324.23   156.28   292.86   238.43   292.86   285.05
324.23
XSP      398.2      324.23
***      LOCBPU(1:n)
XBU      2          5
***      xloc_rcoef rcoef
XRH      0          0.015     113.15   0.015    285.05   0.015
***      bankl      bankr
XOX      113.15    285.05
***      fkec
XFL      0.3        0.1
***      xl         yl        xr        yr
XSL      113.15    324.23   285.05   324.23
***      FLDST      ZDI      QDI ----- cross section    44
XIN      0          0          0
***      location    bec      ninterp   iHotC
XST      146112.19   0          0          0
***      station    elevation data
XSP      0          324.78   135.08   324.78   147.4    292.46   249.8    292.46   263.12
324.78
XSP      398.2      324.78
***      xloc_rcoef rcoef
XRH      0          0.015     135.08   0.015    263.12   0.015
***      bankl      bankr
XOX      135.08    263.12
***      fkec
XFL      0.3        0.1
***      xl         yl        xr        yr
XSL      135.08    324.78   263.12   324.78
***      FLDST      ZDI      QDI ----- cross section    45    check    18
XIN      0          0          0
***      location    bec      ninterp   iHotC
XST      145982.19   0          0          0
***      station    elevation data
XSP      0          325       155.3    325      155.5    292.45   237.3    292.45   237.5
325
XSP      410.2      325
***      xloc_rcoef rcoef
XRH      0          0.015     0          0.015    0          0.015
***      bankl      bankr
XOX      155.3      237.5
***      fkec
XFL      0.3        0.1
***      xl         yl        xr        yr
XSL      0.00E+00   325      0.00E+00   325
***      FLDST      ZDI      QDI ----- cross section    46
XIN      0          0          0
***      location    bec      ninterp   iHotC
XST      145972.19   0          0          0
***      station    elevation data
XSP      0          325.71   139.86   325.71   145.66   292.45   251.57   292.45   257.37
325.71
XSP      397.24    325.71
***      xloc_rcoef rcoef
XRH      0          0.015     139.86   0.015    257.37   0.015
***      bankl      bankr

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XOX      139.86    257.37
***      fkec
XFL      0.3       0.1
***      xl      yr
XSL      139.86   325.71   257.37   325.71
***      FLDST    ZDI      QDI ----- cross section 47
XIN      0          0        0
***      location  bec      ninterp  iHotC
XST      145922.19 0          0        0
***      station  elevation data
XSP      0          325.75  119.93   325.75  154.73   293.17   237.69   293.17   272.49
325.75
XSP      392.42   325.75
***      xloc_rcoef rcoef
XRH      0          0.015   119.93   0.015   272.49   0.015
***      bankl    bankr
XOX      119.93   272.49
***      fkec
XFL      0.3       0.1
***      xl      yr
XSL      119.93   325.75   272.49   325.75
***      FLDST    ZDI      QDI ----- cross section 48 first section
in      pool      19
XIN      0          0        0
***      location  bec      ninterp  iHotC
XST      145872.19 0          0        0
***      station  elevation data
XSP      0          325.8   100     325.8   163.8    293.9    223.8    293.9    287.6
325.8
XSP      387.6    325.8
***      LOCBPU(1:n)
XBD      2          5
***      xloc_rcoef rcoef
XRH      0          0.015   100     0.015   287.6    0.015
***      bankl    bankr
XOX      100       287.6
***      fkec
XFL      0.3       0.1
***      xl      yr
XSL      100       325.8   287.6    325.8
***      FLDST    ZDI      QDI ----- cross section 49
XIN      0          0        0
***      location  bec      ninterp  iHotC
XST      136272.58 0          0        0
***      station  elevation data
XSP      0          325.35  100     325.35  164.49   293.14   224.49   293.14   288.98
325.35
XSP      388.98   325.35
***      LOCBPU(1:n)
XBU      2          5
***      LOCBPU(1:n)
XBD      2          5
***      xloc_rcoef rcoef
XRH      0          0.015   100     0.015   288.98   0.015
***      bankl    bankr
XOX      100       288.98
***      fkec
XFL      0.3       0.1
***      xl      yr
XSL      100       325.35  288.98   325.35
***      FLDST    ZDI      QDI ----- cross section 50
XIN      0          0        0
***      location  bec      ninterp  iHotC
XST      126673.03 0          0        0
***      station  elevation data
XSP      0          324.9   100     324.9   165.18   292.38   225.18   292.38   290.36
324.9
XSP      390.36   324.9
***      LOCBPU(1:n)
XBU      2          5
***      LOCBPU(1:n)
XBD      2          5
***      xloc_rcoef rcoef
XRH      0          0.015   100     0.015   290.36   0.015
***      bankl    bankr
XOX      100       290.36
***      fkec
XFL      0.3       0.1
***      xl      yr
XSL      100       324.9   290.36   324.9
***      FLDST    ZDI      QDI ----- cross section 51

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XIN      0      0      0      0      iHotC
***   location      bec      ninterp      0
XST    117073.5      0      0      0
***   station elevation      data
XSP      0      324.46      100      324.46      165.87      291.62      225.87      291.62      291.74
324.46
XSP      391.74      324.46
***   LOCBPU(1:n)
XBU      2      5
***   LOCBPU(1:n)
XBD      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      100      0.015      291.74      0.015
***   bankl      bankr
XOX      100      291.74
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL      100      324.46      291.74      324.46
***   FLDST      ZDI      QDI ----- cross section      52
XIN      0      0      0      0      iHotC
***   location      bec      ninterp      0
XST    107473.96      0      0      0
***   station elevation      data
XSP      0      324.01      100      324.01      166.56      290.87      226.56      290.87      293.12
324.01
XSP      393.12      324.01
***   LOCBPU(1:n)
XBU      2      5
***   LOCBPU(1:n)
XBD      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      100      0.015      293.12      0.015
***   bankl      bankr
XOX      100      293.12
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL      100      324.01      293.12      324.01
***   FLDST      ZDI      QDI ----- cross section      53
XIN      0      0      0      0      iHotC
***   location      bec      ninterp      0
XST    97874.44      0      0      0
***   station elevation      data
XSP      0      323.56      100      323.56      167.25      290.11      227.25      290.11      294.5
323.56
XSP      394.5      323.56
***   LOCBPU(1:n)
XBU      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      100      0.015      294.5      0.015
***   bankl      bankr
XOX      100      294.5
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL      100      323.56      294.5      323.56
***   FLDST      ZDI      QDI ----- cross section      54
XIN      0      0      0      0      iHotC
***   location      bec      ninterp      0
XST    90184.82      0      0      0
***   station elevation      data
XSP      0      323.47      105.05      323.47      166.68      289.75      228.68      289.75      290.32
323.47
XSP      395.6      323.47
***   xloc_rcoef      rcoef
XRH      0      0.015      105.05      0.015      290.32      0.015
***   bankl      bankr
XOX      105.05      290.32
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL      105.05      323.47      290.32      323.47
***   FLDST      ZDI      QDI ----- cross section      55
XIN      0      0      0      0      iHotC
***   location      bec      ninterp      0
XST    90134.81      0      0      0
***   station elevation      data
XSP      0      324.8      130.27      324.8      161.09      291.03      233.09      291.03      263.91
324.8
XSP      395.6      324.8

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*** xloc_rcoef    rcoef
XRH      0     0.015   130.27   0.015   263.91   0.015
*** bankl    bankr
XOX      130.27  263.91
*** fkec
XFL      0.3     0.1
*** xl      yl      xr      yr
XSL      130.27  324.8   263.91  324.8
*** FLDST    ZDI      QDI -----
of      Check19
XIN      0     0     0
*** location   bec   ninterp   iHotC
XST      90084.81  0     0     0
*** station   elevation   data
XSP      0     326.13  155.3   326.13   155.5   292.3   237.3   292.3   237.5
326.13
XSP      395.6   326.13
*** xloc_rcoef    rcoef
XRH      0     0.015   155.5   0.015   237.5   0.015
*** bankl    bankr
XOX      155.3   237.5
*** fkec
XFL      0.3     0.1
*** xl      yl      xr      yr
XSL      155.5   292.3   237.5   326.13
*** FLDST    ZDI      QDI -----
XIN      0     0     0
*** location   bec   ninterp   iHotC
XST      89974.81  0     0     0
*** station   elevation   data
XSP      0     329     155.3   329     155.5   291.66   237.3   291.66   237.5
329
XSP      395.6   329
*** xloc_rcoef    rcoef
XRH      0     0.015   0     0.015   0     0.015
*** bankl    bankr
XOX      155.5   237.3
*** fkec
XFL      0.3     0.1
*** xl      yl      xr      yr
XSL      0.00E+00  329   0.00E+00  329
*** FLDST    ZDI      QDI -----
XIN      0     0     0
*** location   bec   ninterp   iHotC
XST      89925.59  0     0     0
*** station   elevation   data
XSP      0     324.02  131.71  324.02   159.06   291.01   227.34   291.01   254.69
324.02
XSP      387.89  324.02
*** LOCBPU(1:n)
XBD      2     5
*** xloc_rcoef    rcoef
XRH      0     0.015   131.71  0.015   254.69   0.015
*** bankl    bankr
XOX      131.71  254.69
*** fkec
XFL      0.3     0.1
*** xl      yl      xr      yr
XSL      131.71  324.02  254.69  324.02
*** FLDST    ZDI      QDI -----
XIN      0     0     0
*** location   bec   ninterp   iHotC
XST      88455.5   0     0     0
*** station   elevation   data
XSP      0     321.14  100    321.14   163.8    289.24   213.8    289.24   277.6
321.14
XSP      377.6   321.14
*** LOCBPU(1:n)
XBU      2     5
*** LOCBPU(1:n)
XBD      2     5
*** xloc_rcoef    rcoef
XRH      0     0.015   100    0.015   277.6   0.015
*** bankl    bankr
XOX      100    277.6
*** fkec
XFL      0.3     0.1
*** xl      yl      xr      yr
XSL      100    321.14  277.6   321.14
*** FLDST    ZDI      QDI -----
XIN      0     0     0

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*** location      bec   ninterp   iHotC
XST  81433.16      0       0       0
*** station elevation      data
XSP    0     320.86      100     320.86    163.8    288.96    213.8    288.96    277.6
320.86
XSP    377.6     320.86
*** LOCBPU(1:n)
XBU    2       5
*** LOCBPU(1:n)
XBD    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL    100     320.86    277.6    320.86
*** FLDST      ZDI      QDI -----
after   the      DI
XIN    0       0       0       0
*** location      bec   ninterp   iHotC
XST  75665.28      0       0       1
*** station elevation      data
XSP    0     320.64      100     320.64    163.8    288.74    213.8    288.74    277.6
320.64
XSP    377.6     320.64
*** LOCBPU(1:n)
XBU    2       5
*** LOCBPU(1:n)
XBD    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL    100     320.64    277.6    320.64
*** FLDST      ZDI      QDI -----
cross section      61      Pool      20
XIN    0       0       0       0
*** location      bec   ninterp   iHotC
XST  68399.97      0       0       0
*** station elevation      data
XSP    0     320.57      100     320.57    163.8    288.67    213.8    288.67    277.6
320.57
XSP    377.6     320.57
*** LOCBPU(1:n)
XBU    2       5
*** LOCBPU(1:n)
XBD    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL    100     320.57    277.6    320.57
*** FLDST      ZDI      QDI -----
cross section      62
XIN    0       0       0       0
*** location      bec   ninterp   iHotC
XST  61134.66      0       0       0
*** station elevation      data
XSP    0     320.49      100     320.49    163.8    288.59    213.8    288.59    277.6
320.49
XSP    377.6     320.49
*** LOCBPU(1:n)
XBU    2       5
*** LOCBPU(1:n)
XBD    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL    100     320.49    277.6    320.49
*** FLDST      ZDI      QDI -----
cross section      63
XIN    0       0       0       0

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*** location      bec   ninterp   iHotC
XST  53869.34      0       0       0
*** station elevation      data
XSP    0     320.42      100     320.42    163.8    288.52    213.8    288.52    277.6
320.42
XSP    377.6     320.42
*** LOCBPU(1:n)
XBU    2       5
*** LOCBPU(1:n)
XBD    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL   100     320.42    277.6    320.42
*** FLDST      ZDI      QDI -----
XIN    0       0       0       cross section      65
*** location      bec   ninterp   iHotC
XST  46604.03      0       0       0
*** station elevation      data
XSP    0     320.34      100     320.34    163.8    288.44    213.8    288.44    277.6
320.34
XSP    377.6     320.34
*** LOCBPU(1:n)
XBU    2       5
*** xloc_rcoef   rcoef
XRH    0     0.015      100     0.015    277.6    0.015
*** bankl      bankr
XOX    100     277.6
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL   100     320.34    277.6    320.34
*** FLDST      ZDI      QDI -----
XIN    0       0       0       cross section      66
*** location      bec   ninterp   iHotC
XST  42227.59      0       0       0
*** station elevation      data
XSP    0     320.97      110.09    320.97    162.29    288.91    218.11    288.91    270.31
320.97
XSP    380.87     320.97
*** xloc_rcoef   rcoef
XRH    0     0.015      110.09    0.015    270.31    0.015
*** bankl      bankr
XOX    110.09    270.31
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL   110.09    320.97    270.31    320.97
*** FLDST      ZDI      QDI -----
XIN    0       0       0       cross section      67
*** location      bec   ninterp   iHotC
XST  42184.47      0       0       0
*** station elevation      data
XSP    0     322.65      135.32    322.65    158.52    290.18    228.88    290.18    252.08
322.65
XSP    389.05     322.65
*** xloc_rcoef   rcoef
XRH    0     0.015      135.32    0.015    252.08    0.015
*** bankl      bankr
XOX    135.32    252.08
*** fkec
XFL    0.3     0.1
*** xl        yl      xr      yr
XSL   135.32    322.65    252.08    322.65
*** FLDST      ZDI      QDI -----
XIN    0       0       0       cross section      68      check      20
*** location      bec   ninterp   iHotC
XST  42039.97      0       0       0
*** station elevation      data
XSP    0     325       155.3     325     155.5     290.09    237.3     290.09    237.5
325
XSP    395.6      325
*** xloc_rcoef   rcoef
XRH    0     0.015      0       0.015      0       0.015
*** bankl      bankr
XOX    155.3     237.5
*** fkec      237.3

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XFL      0.3      0.1
***   xl      yl      xr      yr
XSL  0.00E+00      325  0.00E+00      325
***   FLDST      ZDI      QDI ----- cross section 69
XIN      0      0      0
***   location      bec      ninterp      iHotC
XST  41999.97      0      0      0
***   station elevation      data
XSP      0      322.36      133.3      322.36      158.66      290      227.86      290      253.22
322.36
XSP  388.08      322.36
***   xloc_rcoef      rcoef
XRH      0      0.015      133.3      0.015      253.22      0.015
***   bankl      bankr
XOX  133.3      253.22
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL  133.3      322.36      253.22      322.36
***   FLDST      ZDI      QDI ----- cross section 70
XIN      0      0      0
***   location      bec      ninterp      iHotC
XST  41949.97      0      0      0
***   station elevation      data
XSP      0      320.31      105.55      320.31      162.61      288.5      215.81      288.5      272.87
320.31
XSP  378.68      320.31
***   LOCBPU(1:n)
XBD      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      105.55      0.015      272.87      0.015
***   bankl      bankr
XOX  105.55      272.87
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL  105.55      320.31      272.87      320.31
***   FLDST      ZDI      QDI ----- cross section 71
XIN      0      0      0
***   location      bec      ninterp      iHotC
XST  36305.97      0      0      0
***   station elevation      data
XSP      0      320.1      100      320.1      163.4      288.4      213.4      288.4      276.8
320.1
XSP  376.8      320.1
***   LOCBPU(1:n)
XBU      2      5
***   LOCBPU(1:n)
XBD      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      100      0.015      276.8      0.015
***   bankl      bankr
XOX  100      276.8
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL  100      320.1      276.8      320.1
***   FLDST      ZDI      QDI ----- cross section 72
XIN      0      0      0
***   location      bec      ninterp      iHotC
XST  29263.47      0      0      0
***   station elevation      data
XSP      0      320.35      100      320.35      163.4      288.65      213.4      288.65      276.8
320.35
XSP  376.8      320.35
***   LOCBPU(1:n)
XBU      2      5
***   LOCBPU(1:n)
XBD      2      5
***   xloc_rcoef      rcoef
XRH      0      0.015      100      0.015      276.8      0.015
***   bankl      bankr
XOX  100      276.8
***   fkec
XFL      0.3      0.1
***   xl      yl      xr      yr
XSL  100      320.35      276.8      320.35
***   FLDST      ZDI      QDI ----- cross section 73
XIN      0      0      0
***   location      bec      ninterp      iHotC
XST  22220.97      0      0      0

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***      station elevation      data
XSP       0      320.6      100      320.6      163.4      288.9      213.4      288.9      276.8
320.6
XSP       376.8      320.6
***      LOCBPU(1:n)
XBU       2      5
***      LOCBPU(1:n)
XBD       2      5
***      xloc_rcoef      rcoef
XRH       0      0.015      100      0.015      276.8      0.015
***      bankl      bankr
XOX       100     276.8
***      fkec
XFLL      0.3      0.1
***      xl      yl      xr      yr
XSL       100     320.6     276.8     320.6
***      FLDST      ZDI      QDI ----- cross section      74
XIN       0      0      0
***      location      bec      ninterp      iHotC
XST       15178.47    0      0      0
***      station elevation      data
XSP       0      320.85      100      320.85      163.4      289.15      213.4      289.15      276.8
320.85
XSP       376.8      320.85
***      LOCBPU(1:n)
XBU       2      5
***      LOCBPU(1:n)
XBD       2      5
***      xloc_rcoef      rcoef
XRH       0      0.015      100      0.015      276.8      0.015
***      bankl      bankr
XOX       100     276.8
***      fkec
XFLL      0.3      0.1
***      xl      yl      xr      yr
XSL       100     320.85     276.8     320.85
***      FLDST      ZDI      QDI ----- cross section      75
XIN       0      0      0
***      location      bec      ninterp      iHotC
XST       8321.09    0      0      0
***      station elevation      data
XSP       0      319.79      100      319.79      160.91      289.33      210.91      289.33      271.82
319.79
XSP       371.82     319.79
***      LOCBPU(1:n)
XBU       2      5
***      LOCBPU(1:n)
XBD       2      5
***      xloc_rcoef      rcoef
XRH       0      0.015      100      0.015      271.82      0.015
***      bankl      bankr
XOX       100     271.82
***      fkec
XFLL      0.3      0.1
***      xl      yl      xr      yr
XSL       100     319.79     271.82     319.79
***      FLDST      ZDI      QDI ----- cross section      76 Section      U/s
of
XIN       0      0      0
***      location      bec      ninterp      iHotC
XST       1510     0      0      0
***      station elevation      data
XSP       0      318.4      100      318.4      157.8      289.5      207.8      289.5      265.6
318.4
XSP       365.6      318.4
***      LOCBPU(1:n)
XBU       2      5
***      xloc_rcoef      rcoef
XRH       0      0.015      100      0.015      265.6      0.015
***      bankl      bankr
XOX       100     265.6
***      fkec
XFLL      0.3      0.1
***      xl      yl      xr      yr
XSL       100     318.4     265.6     318.4
***      FLDST      ZDI      QDI ----- cross section      77
XIN       0      0      0
***      location      bec      ninterp      iHotC
XST       1230     0      0      0
***      station elevation      data

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XSP          0    319.98    120.81    319.98    156.94    289.5    218.94    289.5    255.06
319.98
XSP          376.85   319.98
*** xloc_rcoef rcoef
XRH          0     0.015    120.81     0.015    255.06     0.015
*** bankl bankr
XOX          120.81   255.06
*** fkec
XFL          0.3      0.1
*** xl      yl      xr      yr
XSL          120.81   319.98   255.06   319.98
*** FLDST   ZDI      QDI ----- cross section      78 section      U/S
of Check21
XIN          0     0     0
*** location bec ninterp iHotC
XST          1180     0     0     0
*** station elevation data
XSP          0     322.6    120.4     322.6    155.5    289.5    217.5    289.5    255.5
322.6
XSP          395.6    322.6
*** xloc_rcoef rcoef
XRH          0     0.015    155.5     0.015    237.5     0.015
*** bankl bankr
XOX          155.3    237.5
*** fkec
XFL          0.3      0.1
*** xl      yl      xr      yr
XSL          155.5    289.5    237.5    322.6
*** FLDST   ZDI      QDI ----- cross section      79 check      21
XIN          0     0     0
*** location bec ninterp iHotC
XST          1070     0     0     0
*** station elevation data
XSP          0     322.6    155.3     322.6    155.5    289.5    237.3    289.5    237.5
322.6
XSP          395.6    322.6
*** xloc_rcoef rcoef
XRH          0     0.015     0     0.015     0     0.015
*** bankl bankr
XOX          155.3    237.5
*** fkec
XFL          0.3      0.1
*** xl      yl      xr      yr
XSL          0.00E+00   325    0.00E+00   325
*** FLDST   ZDI      QDI ----- cross section      80
XIN          0     0     0
*** location bec ninterp iHotC
XST          267.5     0     0     0
*** station elevation data
XSP          0     317.2    113.88    317.2    157.23   287.25   215.23   287.25   258.58
317.2
XSP          373.1    317.2
*** xloc_rcoef rcoef
XRH          0     0.015    113.88    0.015    258.58     0.015
*** bankl bankr
XOX          113.88   258.58
*** fkec
XFL          0.3      0.1
*** xl      yl      xr      yr
XSL          113.88   317.2    258.58   317.2
*** FLDST   ZDI      QDI ----- cross section      81 last section
in the simulation Pool22
XIN          0     0     0
*** location bec ninterp iHotC
XST          0     0     0     0
*** station elevation data
XSP          0     315.4    100      315.4    157.8    286.5    207.8    286.5    265.6
315.4
XSP          365.6    315.4
*** xloc_rcoef rcoef
XRH          0     0.015     100     0.015    265.6     0.015
*** bankl bankr
XOX          100     265.6
*** fkec
XFL          0.3      0.1
*** xl      yl      xr      yr
XSL          100     315.4    265.6    315.4
*** End of River 1
*** Start input of sediment transportment
*** theta ntsedf nresponse
YST          1       1       1

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***      drl      dru      bdin
YSG    0.004    0.074      0
YSG    0.074    0.15       0
YSG    0.15     0.3        0
YSG     0.3      1        0
*** Start of River 1
***      nts
USB      4
***      TSI      QSI      1431
US4      0      1431
USA4    796      1431
***      QI      PISED
USS    2000     0.96     0.01     0.01     0.02
USS    3000     0.96     0.01     0.01     0.02
*** NKQS(J) non-point flow source
LNS      1
*** X1QS(J,nk) X2QS(J,nk) lat type
LSL 192414.5 180000      5      Lateral      1
***      t4      st4
***      0.7   1.00E-01      0.1      0.1
LS5    200     0.0      0.0      0.0      0.0
LS5    204     0.0      0.0      0.0      0.0
LS5    208     0.0      0.0      0.0      0.0
LS5    216    14.0      4.0      4.0      4.0
LS5    232    54.3     15.5     15.5     15.5
LS5    264   209.4     59.8     59.8     59.8
LS5    272  3962.7   1132.2   1132.2   1132.2
LS5    276 13563.0   3875.1   3875.1   3875.1
LS5    280 18691.7   5340.5   5340.5   5340.5
LS5    284 23459.8   6702.8   6702.8   6702.8
LS5    292 27226.2   7778.9   7778.9   7778.9
LS5    296 28800.9   8228.8   8228.8   8228.8
LS5    312 27226.2   7778.9   7778.9   7778.9
LS5    412 23459.8   6702.8   6702.8   6702.8
LS5    416 18691.7   5340.5   5340.5   5340.5
LS5    420 16459.9   4702.8   4702.8   4702.8
LS5    424 13563.0   3875.1   3875.1   3875.1
LS5    428 10798.3   3085.2   3085.2   3085.2
LS5    432  8133.8   2323.9   2323.9   2323.9
LS5    444  3646.2   1041.8   1041.8   1041.8
LS5    456  2384.0    681.2    681.2    681.2
LS5    596  1682.9    480.8    480.8    480.8
LS5    600     0.0      0.0      0.0      0.0
LS5   600.1     0.0      0.0      0.0      0.0
BP2  386230.9 324405.6 195743.2
***      PTMP
BLP    0.960    0.010    0.010    0.020
BLP    0.960    0.010    0.010    0.020
BLP    0.960    0.010    0.010    0.020
***      ttin      temp
TMP      0      67.83
***      FIO
***      crosmmin_er      crosmmax      ercrosmmin_d      crosmmax_d      botmin      botmax
FIM    158    246      0      10000     306.6     9999      !section      1
FIM    158    246      0      10000     305.81    9999      !section      2
FIM    161    247      0      10000     304.33    9999      !section      3
FIM    164    252      0      10000     302.39    9999      !section      4
FIM    164    252      0      10000     301.4     9999      !section      5
FIM    159    257      0      10000     300.65    9999      !section      6
FIM    153    263      0      10000     301.7     9999      !section      7
FIM    153    263      0      10000     303.2     9999      !section      8
FIM   155.4   237.4    0      10000     302.98    9999      !section      9
FIM    155    259      0      10000     302.75    9999      !section     10
FIM    163    244      0      10000     300.88    9999      !section     11
FIM    167    240      0      10000     300.5     9999      !section     12
FIM    167    240      0      10000     299.6     9999      !section     13
FIM    169    240      0      10000     299.53    9999      !section     14
FIM    168    246      0      10000     299.2     9999      !section     15
FIM    168    245      0      10000     300.53    9999      !section     16
FIM    167    245      0      10000     298.52    9999      !section     17
FIM    165    242      0      10000     297.58    9999      !section     18
FIM    164    242      0      10000     296.16    9999      !section     19
FIM    164    242      0      10000     295.56    9999      !section     20
FIM    161    245      0      10000     295.76    9999      !section     21
FIM    152    254      0      10000     297.16    9999      !section     22
FIM   155.4   237.4    0      10000     296.68    9999      !section     23
FIM    157    248      0      10000     296.19    9999      !section     24
FIM    164    242      0      10000     294.76    9999      !section     25
FIM    165    243      0      10000     293.92    9999      !section     26
FIM    166    243      0      10000     293.07    9999      !section     27

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FIM      166      244      0     10000    292.52    9999    !section      28
FIM      166      244      0     10000    291.9     9999    !section      29
FIM      166      244      0     10000    291.4     9999    !section      30
FIM      160      250      0     10000    293.11    9999    !section      31
FIM      152      258      0     10000    295.25    9999    !section      32
FIM      155.4    237.4    0     10000    295.45    9999    !section      33
FIM      149      258      0     10000    295.66    9999    !section      34
FIM      155      246      0     10000    293.48    9999    !section      35
FIM      160      232      0     10000    291.3     9999    !section      36
FIM      160      232      0     10000    291.14    9999    !section      37
FIM      160      232      0     10000    291.67    9999    !section      38
FIM      160      232      0     10000    292       9999    !section      39
FIM      160      232      0     10000    292.32    9999    !section      40
FIM      160      232      0     10000    292.65    9999    !section      41
FIM      160      232      0     10000    292.97    9999    !section      42
FIM      155      239      0     10000    292.86    9999    !section      43
FIM      146      251      0     10000    292.46    9999    !section      44
FIM      155.4    237.4    0     10000    292.45    9999    !section      45
FIM      144      252      0     10000    292.45    9999    !section      46
FIM      153      239      0     10000    293.17    9999    !section      47
FIM      162      225      0     10000    293.9     9999    !section      48
FIM      163      226      0     10000    293.14    9999    !section      49
FIM      164      226      0     10000    292.38    9999    !section      50
FIM      164      226      0     10000    291.62    9999    !section      51
FIM      165      228      0     10000    290.87    9999    !section      52
FIM      166      228      0     10000    290.11    9999    !section      53
FIM      165      230      0     10000    289.75    9999    !section      54
FIM      160      234      0     10000    291.03    9999    !section      55
FIM      155.4    237.4    0     10000    292.3     9999    !section      56
FIM      155.4    237.4    0     10000    291.66    9999    !section      57
FIM      158      228      0     10000    291.01    9999    !section      58
FIM      162      215      0     10000    289.24    9999    !section      59
FIM      162      215      0     10000    288.96    9999    !section      60
FIM      162      215      0     10000    288.74    9999    !section      61
FIM      162      215      0     10000    288.67    9999    !section      62
FIM      162      215      0     10000    288.59    9999    !section      63
FIM      162      215      0     10000    288.52    9999    !section      64
FIM      162      215      0     10000    288.44    9999    !section      65
FIM      161      220      0     10000    288.91    9999    !section      66
FIM      157      230      0     10000    290.18    9999    !section      67
FIM      155.4    237.4    0     10000    290.09    9999    !section      68
FIM      157      229      0     10000    290       9999    !section      69
FIM      161      217      0     10000    288.5     9999    !section      70
FIM      162      215      0     10000    288.4     9999    !section      71
FIM      162      215      0     10000    288.65    9999    !section      72
FIM      162      215      0     10000    288.9     9999    !section      73
FIM      162      215      0     10000    289.15    9999    !section      74
FIM      160      212      0     10000    289.33    9999    !section      75
FIM      156      209      0     10000    289.5     9999    !section      76
FIM      155      220      0     10000    289.5     9999    !section      77
FIM      154      219      0     10000    289.5     9999    !section      78
FIM      155.4    237.4    0     10000    289.5     9999    !section      79
FIM      156      217      0     10000    287.25    9999    !section      80
FIM      156      209      0     10000    286.5     9999    !section      81
***      nstube      wfrac
STU      1        0.8
***      imin      ilength
SMN      0        0
***      ised
SEQ      4
***      xc
SA2      386230.91 324405.62 195743.16
***      angle1(abovangle2(belnalt)      alphad      alphas      blength      wt      dep      dlong      dtrans
SAT      90        90      200      0.05      1        0        0        0        0
SAT      90        90      200      0.05      1        0        0        0        0
SAT      90        90      200      0.05      1        0        0        0        0
***      xc
CS2      0.00      1.00
***      stdep_f      stdep_p      concEq      er_lim
CSD      0.005     0.005     0.85      0.1
CSD      0.005     0.005     0.85      0.1
***      xc
CE2      0.00      1.00
***      stpero      er_stme      stmero      er_mass
CER      0.005     7.0000    0.01      10
CER      0.005     7.0000    0.01      10
***      fvform
CFO      1
***      densC_I      densC_f      densC_e      time_e
CSC      77.98     101.30    81.86     1000.00
***      xc

```

```

CD2      386230.91 324405.62 195743.16      100000
*** densityClay0
CDI      78.00
CDI      78.00
CDI      78.00
CDI      78.00
CDI      78.00
*** End of River 1
*** end message
END

```

## D3.2 Output Data Files

The output files are too long to be included in this section. They can be found under directory Example3 in the GSTAR-1D distribution.

## D3.3 Final Remarks

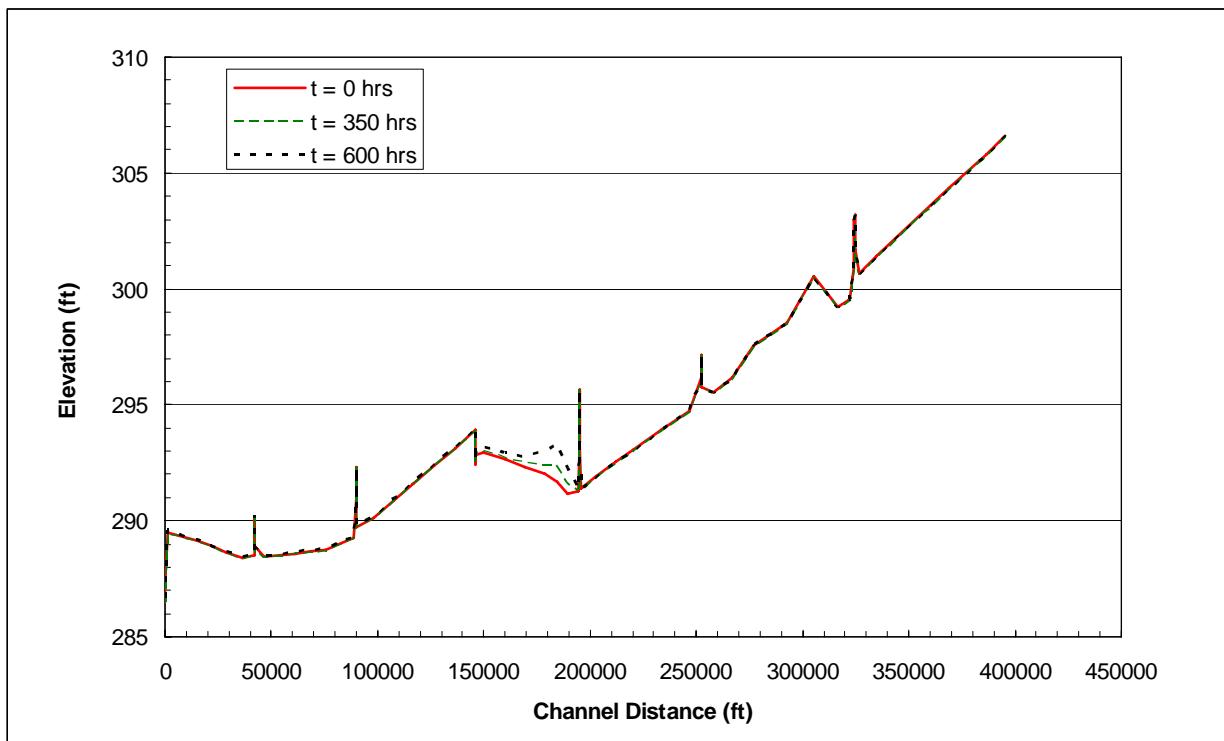


Figure D3.1 Bed elevation change of the SLC before and after a flood event.

Figure D3.1 shows the bed elevations before and after the flood. The sediments allowed into the aqueduct are deposited just downstream of the inlet, raising the channel bed elevation. The sediments are eroded after the flood, and the bed geometry returns to its initial form after the flood.

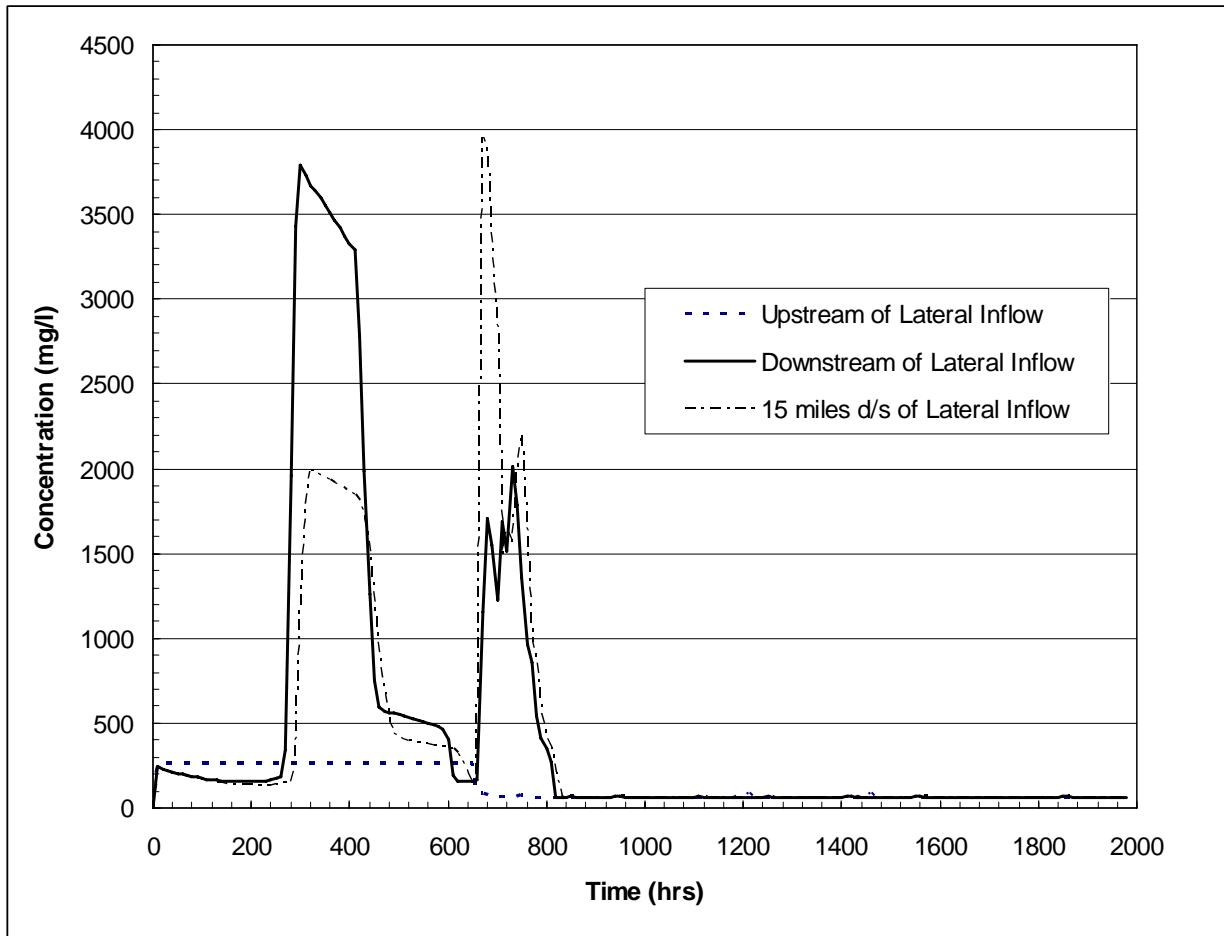


Figure D3.2 Sediment concentration changes with time

Figure D3.2 shows concentration changes with the sediment lateral inflow. The peak sediment inflow concentration just downstream of the lateral inflow is about 3800 mg/l. The baseline condition prior to the lateral sediment inflow is 265 mg/l. After time of about 700 hr, the concentration just downstream of the lateral inlet increases to 2000 mg/l. This increase is due to the increase in flow rate that erodes sediment that was deposited by the lateral inflow. Fifteen miles downstream of the lateral inflow the concentration increases to almost 4000 mg/l at 700 hours.